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## Monumental Computations

### Digital archaeology of large urban and underground infrastructures

Proceedings of the 24th International Conference on Cultural Heritage and New Technologies 2019.
CHNT 24, 2019

Edited by
Wolfgang Börner | Christina Kral-Börner | Hendrik Rohland

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## Proceedings of the International Conference on Cultural Heritage and New Technologies, Vienna

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# Preface

In most countries large urban development projects pose a challenge for organizations and individuals whose aim it is to preserve as much of the cultural heritage in the cities concerned as possible. Computational approaches are indispensable in all steps of a large urban development project because they

- assist monument protection agencies in collaboration with urban planners to find the optimal compromise in terms of urban needs and preservation of known cultural heritage.
- support the efficient documentation of monuments and archaeological sites before their destruction in the course of urban development activities
- include new and attractive methods of informing the public.

Major infrastructure projects have the potential to create significant new knowledge in cultural heritage, especially in archaeological research. These projects are a real challenge for cultural heritage institutions that seek to document/preserve as much of the cultural heritage in the area considered. Ideally, cultural heritage institutions are involved in all phases of these projects including planning, implementing, and dissemination of the results in terms of new cultural heritage information. Due to their large scale and the often accompanying time pressure, the various tasks involving cultural heritage data management of large construction projects can drive innovation. In the planning phase, it is important to assess different alternatives based on known cultural heritage data. This assessment is often supplemented by commissioning prospection activities in areas where reliable data is not yet available. All cultural heritage sites destroyed in the course of a construction project must be adequately recorded before destruction. In this situation, cultural heritage institutions face new challenges such as excavations in tunnels, coordinating several excavation teams, dealing with sophisticated urban stratigraphy, large amounts of finds as well as large analogue and digital datasets.

The CHNT Committee

# Keynote: Belowthesurface

## Archaeology of the river Amstel in Amsterdam during the North/Southline metro construction and its analogue and digital spinoff

*Jerzy GAWRONSKI, Monuments and Archaeology, City of Amsterdam*

**Abstract:** Between 2003 and 2009 several archaeological excavations have been organized during the construction of the new North/Southline metro in Amsterdam. The basic theme of the research was a new urban material history, based on the large quantity of finds (c. 700,000) which were recovered from the former riverbed at Rokin and Damrak in the centre of the city where the metro was built. The river is analysed and interpreted as a new source of archaeological data on urban life from 1200 until the present day. The archaeological data created by the river provides, through its spatial context, new perspectives on the material interpretation of the city's history. The methods and outcome of this city archaeology project are discussed together with its analogue and digital products, such as, the photo atlas *Stuff* with 13,000 finds, the public display of 10,000 finds in two showcases in Station Rokin and the website Belowthesurface.amsterdam with 20,000 finds.

***Keywords:*** *Amsterdam—metro—river archaeology—digital archaeology—website*

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## Metro

The North/South line is a 9.7 km metro connection between the north and south of Amsterdam, which is separated by the IJ, the ancient harbour in front of the historical town. The 7.1 km long underground route in the historic city centre where possible followed the existing open infrastructure to avoid damaging buildings. The open spaces in the centre consist of streets but also of (partly open and partly filled in) waterways (Fig. 1).

The tunnels were drilled at a depth of 20 to 30 metres, below NAP (Amsterdam Ordnance Datum defining the city's normal water level), and below the wooden foundation piles of the buildings next to the metro route, which are at an average of 12 metres below NAP. From a civil engineering point of view, the building project was highly innovative and even experimental, as at the time, there was no previous experience of boring tunnels through a soft subsoil of sand and clay in a historic city centre like Amsterdam.

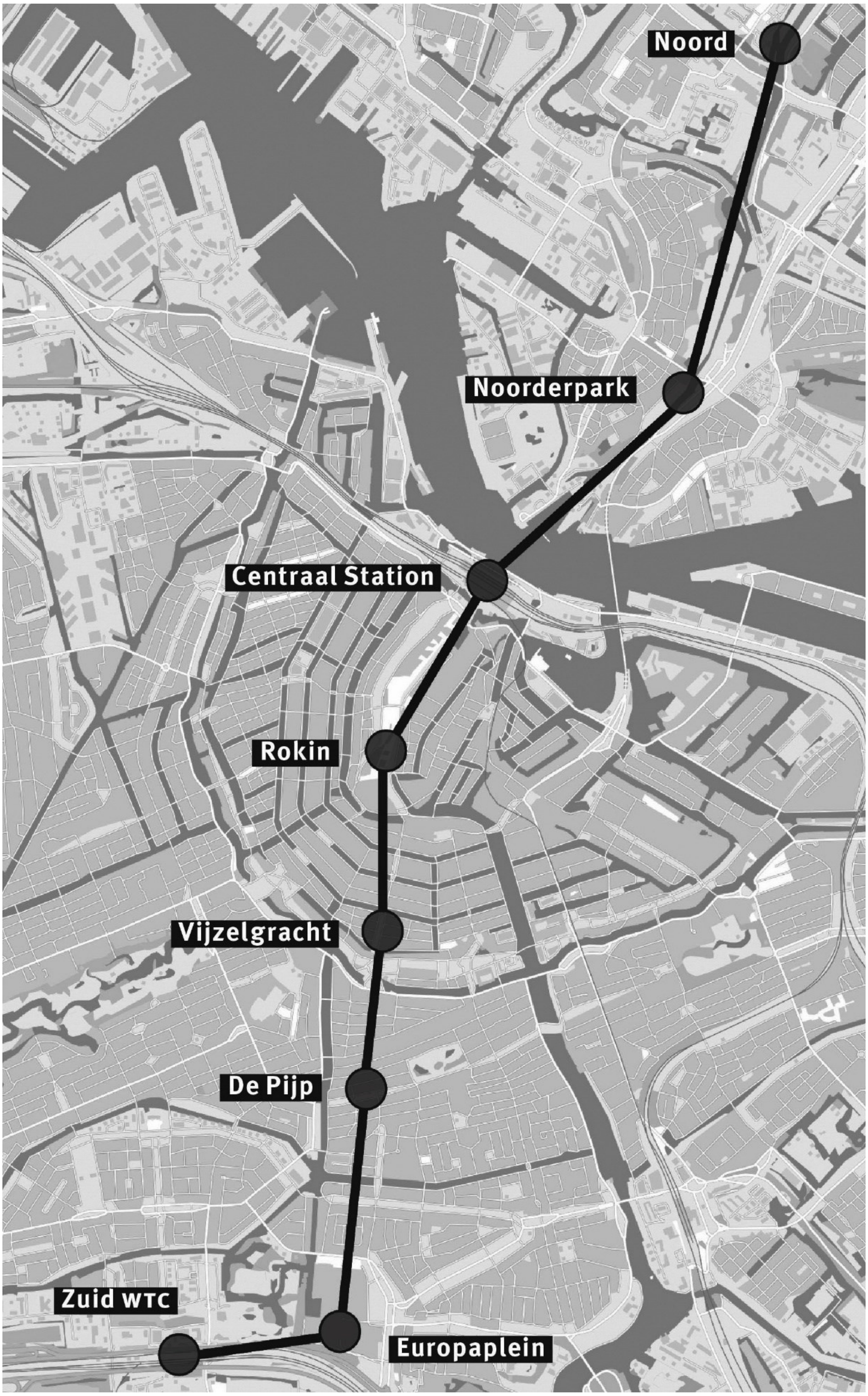



*Fig. 1. Route of the North/Soutline metro. The Damrak building site is part of Station Centraal Station, situated together with rokin and Vijzelgracht in the historical centre of Amsterdam (Gawronski et al. 2018, p. 12: design Willem van Zoetendaal)*

The challenges of the North/South line were not confined to civil engineering, but applied equally to archaeological research, which was organised by the office of Monuments and Archaeology of the city of Amsterdam and formed an integral part of the construction programme. The archaeological implications for the construction sites in the city centre were assessed in the early stages of planning. The tunnel itself was not the primary archaeological site, as is it was technically impossible for archaeologists to work ahead of the tunnel boring machine. The tunnel cuts through different levels from several landscape periods dating from 124,000 to 10,000 BC (the geological epoch of the late Pleistocene). Between roughly 12 and 25 metres below NAP the soil layers belong to a steppe landscape (Weichselian or the last Ice Age period, c. 114,000–10,000 BC) and from approximately 25 metres below NAP the shores of a warm sea, the Eemian Sea (Eemian, c. 124,000–114,000 BC). The archaeological research focused on the soil layers in the upper 12 metres of the six vertical excavation pits for the stations along the route, belonging to the Holocene epoch (10,000 BC till present).

## River archaeology

Four of the six construction sites which were selected for archaeology were situated in former or existing streambeds (Stationsplein, Damrak, Rokin and Vijzelgracht). The two main sites were Damrak and Rokin, which yielded 99 % of all finds (Fig. 2).

These sites make the archaeological project of the North/South line essentially a river archaeology project, involving a systematic examination of the bed of the River Amstel (Gawronski et al., 2010). Streambeds had significant archaeological potential because of the simple fact that material remains can sink to the bottom of rivers, canals or open water and can accumulate in large quantities over time, depending on the degree of dynamics of the water environment (current, sedimentation etc).

Archaeologists were first alerted to the research potential of streambeds by the nascent discipline of underwater archaeology in the 1960's. The upsurge of finds and discoveries from lakes, rivers, canals and their banks raised general awareness of the scientific value of streambeds as repositories of archaeological finds, while excavations of reclaimed waterways and harbours served to strengthen this idea. In Amsterdam several excavations have demonstrated the archaeological potential of landfilled banks (Jayasena, 2020). Elsewhere, recent metro construction projects that transected water zones have yielded a plethora of deposits, such as the excavations of the Byzantine Harbour of Theodosius in Istanbul during the construction of Yenikapi metro station in 2004–2013 (Kocabaş, 2015), or those of the Roman harbour in the Rhine in Cologne while building the Nord-Süd Bahn in 2003–2012. The special archaeological nature of banks and underwater sites has not only been recognised by science, but even in art. Of significance is Mark Dion's *Tate Thames Dig* in 1999. Dion used the banks of the River Thames in London as a backdrop for an archaeological installation by collecting finds there at low tide, thereby representing the river as a material source (Coles et al., 1999).

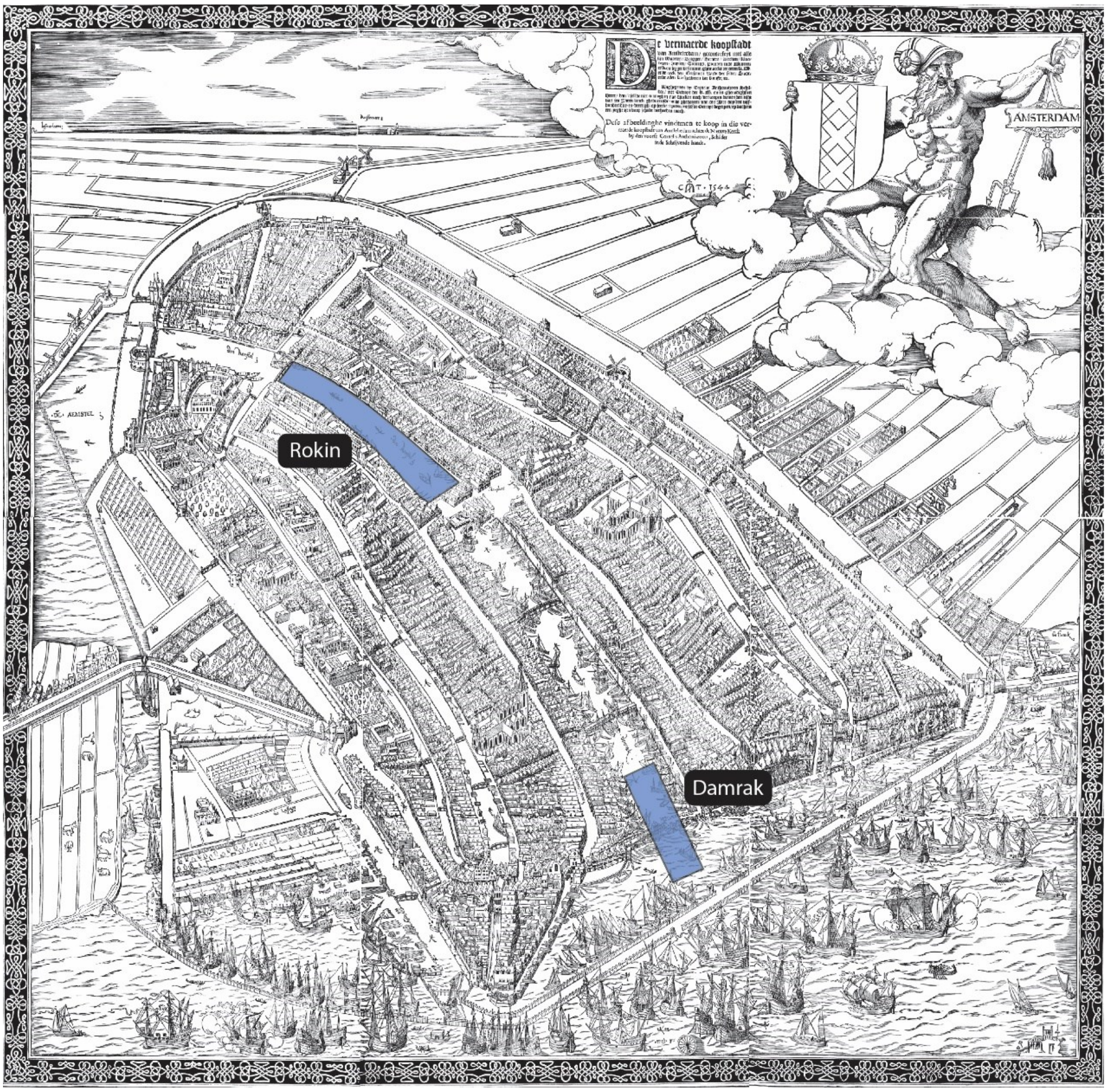



*Fig. 2. Historical map of Amsterdam by Amsterdam by Cornelis Anthonisz from 1544 with the River Amstel as the vital artery of the city (Amsterdam City Archives, 010001001032). The tunnel of the North/South line follows the open waterway of the Amstel in the historical city centre and the construction sites of Damrak and Rokin are situated in the riverbed (Gawronski et al. 2018, p. 14: design Willem van Zoetendaal)*

By far the largest group of archaeological finds from these riverbed sites is linked to a universal aspect of human behaviour, namely the habit of dumping waste in water. It is an easy way of getting rid of waste, as it immediately disappears out of sight or is carried away by the current. This waste, specifically in an urban setting, can be extremely varied, of both domestic and artisanal or industrial origin. As such, it can be spatially related to activities which are associated with a building or structure, workshop or installation along the bank. Apart from archaeological remains which are connected with activities ashore, there is also a category of water finds which are primarily associated with shipping activities that vary from items that have fallen overboard, to complete shipwrecks and parts of ships. Yet another group consists of items, mostly personal belongings, that were not dumped intentionally but were somehow lost accidentally in the water.

Apart from the physical aspect of archaeological material sinking down in water, underwater deposits differ from deposits on land, in the diverse origin and generally mixed nature of the finds. The chance of finding concentrations of material remains is highest in the beds of urban canals due to high habitation density and the frequency with which inhabitants and workshops discarded their unwanted 'stuff' in the water. In a water-rich city such as Amsterdam, this was certainly the case. The city's many historical rulings on the disposal of waste in waterways go back as far as the fifteenth century and clearly attest to the widespread practice of this illegal form of waste disposal and the difficulty in curbing it.

**Fieldwork on Damrak and Rokin**

Different techniques were applied in the archaeological fieldwork to retrieve as many finds as possible during the civil engineering operations. Archaeology had to be integrated in the building process, which was large scale, complex and technologically advanced. Depending on the specific building scheme a certain archaeological solution was chosen. On Damrak for example the construction process involved sinking a concrete caisson of approximately 60 × 20 metres, constructed in the existing open water on the bed of the Damrak, to a depth of 25 metres. The civil engineering excavation process consisted of liquefying the soil beneath the caisson with high-pressure water cannons with water and pumping the mixture of soil and water through tubes to a discarding system. The working chamber beneath the caisson was kept pressurised to keep out the groundwater. The pressurisation limited the working time underneath the caisson for construction workers and archaeologists alike.

The on site archaeological documentation was achieved by accompanying each jetty engineering team by an archaeologist, and having a separate team of archaeologists worked in the evening at the end of sinking operations to document in detail the finds and underground soil context. In order to guarantee the maximum retrieval of finds while jetting operations were in progress, a large size industrial sieve was connected to the drain pipes. The sieve had two decks with different sized mesh (upper deck 4 × 4 cm, lower deck 1 × 1 cm) that caught any finds larger than a centimetre from the ejected slurry. A separate team of archaeologists operated the sieve and managed to gather 465,536 finds (43,045 records in the find database), originating from an excavation area of only 60 × 20 metres and c. 12 metres deep (the underside of the riverbed).

The Rokin building site consisted of a box like structure of deep walls (30 metres deep), measuring 190 × 25 metres, for the underground station. The entire space had to be excavated to reach the future metro platform level, at a depth of 27 meters below NAP, where the tunnel drill would enter the station. The excavation was executed in five 3-month phases. During each phase a 4–5-metre-high layer of soil was removed over the whole length of the pit from south to north. At a soil depot an archaeological team sifted through the soil for finds, looking especially for small metal finds using metal detectors. The archaeological operation on site concentrated on the first 3 phases of excavation, as the riverbed of the Amstel on the Rokin had an estimated depth of 12 metres. The richest find deposits in the river were uncovered during the excavation to approximately 6.5 metres below NAP related to soil deposition from the 16$^{th}$ to the 19$^{th}$ century. The stratigraphic position and depth of the finds in the different layers were documented with over 100 cross-section drawings of the Amstel fill. The horizontal distribution of the finds was recorded using a grid system which was linked with the actual building layout on the banks on either side of the river. By integrating the geological stratigraphy and the finds distribution in a 3D GIS, the archaeological finds could be linked to their provenance inside the river and to historical buildings on either side of the Rokin. The archaeological research at Rokin ultimately yielded 229,943 finds (90,258 records in the find database).

## Processing the finds

Altogether a total of 697,235 archaeological finds were retrieved from the six sites (Table 1). This included complete objects and numerous fragments. These are documented in 134,282 individual records in a digital relational database which is compiled from multiple separate data tables. Each record consists of a number of fields in which the separate attributes of a find are recorded, each based on a specific data table.

| Site | Number of finds | % | Number of records | Total weight (gr) |
|---|---|---|---|---|
| Damrak NZD1 | 465,536 | 667 | 43,045 | 8,010,552 |
| Rokin NZR1 and NZR2 | 229,943 | 33 | 90,258 | 13,347,833 |
| Other sites | 1,756 | 03 | 979 | 344,719 |
| | | | | |
| Total | 697,235 | 100 | 134,282 | 21,703,104 |

*Table 1. The total number of archaeological finds from Damrak, Rokin and other sites of the North/South line project, including the number of records in the database and the total weight of the finds (Gawronski et al. 2018, p. 20: design Willem van Zoetendaal)*

In principle, one record contains two categories of information: fieldwork data and object data. Fieldwork data is practical and concerns for instance, the date on which the find was made or the location within the excavation, such as in which layer or at which depth (stratigraphic indication), or where in the horizontal section. Object data is more varied and relates in the first place to the perceived attributes of a find, such as its dimensions, material, production method, type of decoration (important for differentiating pottery, for example), the number of fragments or parts within a record (sherds of a single pot, for instance) or the extent to which an object is complete. A second group of object data is derived from specialist interpretation. This extrinsic data concerns the find’s functional, chronological and spatial attributes (Gawronski, 2012, pp. 8–13). Functional data records what an object was used for. A functional reconstruction of the find is one of the primary goals of artefact studies. These functional interpretations may vary in complexity. The most basic functional meaning is to define the purpose of the complete original object as archaeological finds in general are broken and consist of fragments. So when a find consists of the foot of a vase, the function of the object is given as ‘vase’ and not ‘foot’. A second functional meaning is linked to the broader context in which the artefact was used, for instance a household item. These functional features serve to create larger categories of finds. To the functional feature meaning, the chronology of the find can be added. The chronological attribute is determined by the year or time period when it was made or used. A date can be deduced from the object itself because it is representative of a certain type from a certain period, or from its relation with other finds of known date, which thus provide a relational chronology. The spatial non-fieldwork features relate to the location where the object was made or in case of import, its place of origin, which in turn can be linked with the type of material and the production technique. This applies in particular to pottery; for example, if the material is porcelain the place of origin could be China.

### Damrak and Rokin data

The finds data can be used to compare both sites, which are each situated in a different topographical river context: Damrak at the mouth of the River Amstel and Rokin in the river section in the urban heart of Amsterdam. An initial distinction can be made on numerical grounds: the yield of 465,536 finds from the riverbed at Damrak is double that of the 229,943 finds from the entire excavation at Rokin, which constitute respectively 66.7 % and 33 % of the total yield from all the research sites put together. Comparison of the types of material reveals a similar picture of the type of objects—waste—that were disposed of in the river at both locations (Table 2).

The bulk of the finds in both cases consist of ceramics (350,491), followed by bone (126,367), metal (91,849), leather (58,597), clay pipe (26,225), glass (21,218) and building ceramics (10,405). There were very few finds in any of the other categories. However, there were also differences between them. Although there were half as many finds at Rokin, the average weight per find at Rokin was 3.5 times greater than that of the Damrak finds. The difference in weight indicates that the finds at Damrak were more fragmented. These simple comparisons of quantity and weight offer an initial indication of the different waste disposal practices at the two locations: at the mouth of the river the disposal of bulk waste and in the city centre the disposal of complete household items. Another factor determining the statistical outcome is the collection method. The sieve with the 1 × 1cm mesh yielded a comparatively large number of small finds, including a relatively large number of virtually indestructible metal objects.

| Category | Damrak number of finds | Damrak number of records | Damrak weight (gr) | Rokin number of finds | Rokin number of records | Rokin weight (gr) |
|---|---|---|---|---|---|---|
| CER (ceramics) | 201,823 | 16,947 | 3,326,919 | 148,668 | 50,334 | 8,581,922 |
| FAU (fauna) | 111,198 | 4,538 | 2,889,223 | 15,169 | 3,948 | 947,878 |
| MTL (metal) | 74,867 | 10,308 | 1,221,127 | 16,982 | 14,556 | 834,118 |
| LEE (leather) | 45,775 | 2,278 | 2,939 | 12,822 | 5,255 | 6,451 |
| CPY (pipe clay) | 15,088 | 3,239 | 898 | 11,137 | 6,382 | 3,195 |
| GLS (glass) | 7,586 | 1,674 | 88,389 | 13,632 | 4,971 | 784,453 |
| BWM (building ceramics) | 2,494 | 880 | 133,788 | 7,911 | 2,949 | 971,760 |
| HT (wood) | 1,175 | 985 | 167,714 | 810 | 627 | 25,925 |
| KSC (clay sculpture) | 120 | 120 | 2,196 | 7 | 6 | 383 |
| KST (synthetics) | 641 | 369 | 7,697 | 51 | 42 | 2,320 |
| PLT (botanical) | 1,790 | 270 | 5,064 | 536 | 166 | 4,483 |
| STN (stone) | 1,032 | 514 | 110,317 | 1,468 | 437 | 1,133,720 |
| TW (rope) | 73 | 51 | 326 | 133 | 101 | 2,791 |
| TXT (textile) | 753 | 585 | 10,895 | 389 | 289 | 2,162 |
| VST (flint) | 549 | 137 | 27,702 | 1 | 1 | 11 |
| Other | 572 | 150 | 15,358 | 227 | 194 | 46,261 |
| | | | | | | |
| Total | 465,536 | 43,045 | 8,010,552 | 229,943 | 90,258 | 13,347,833 |

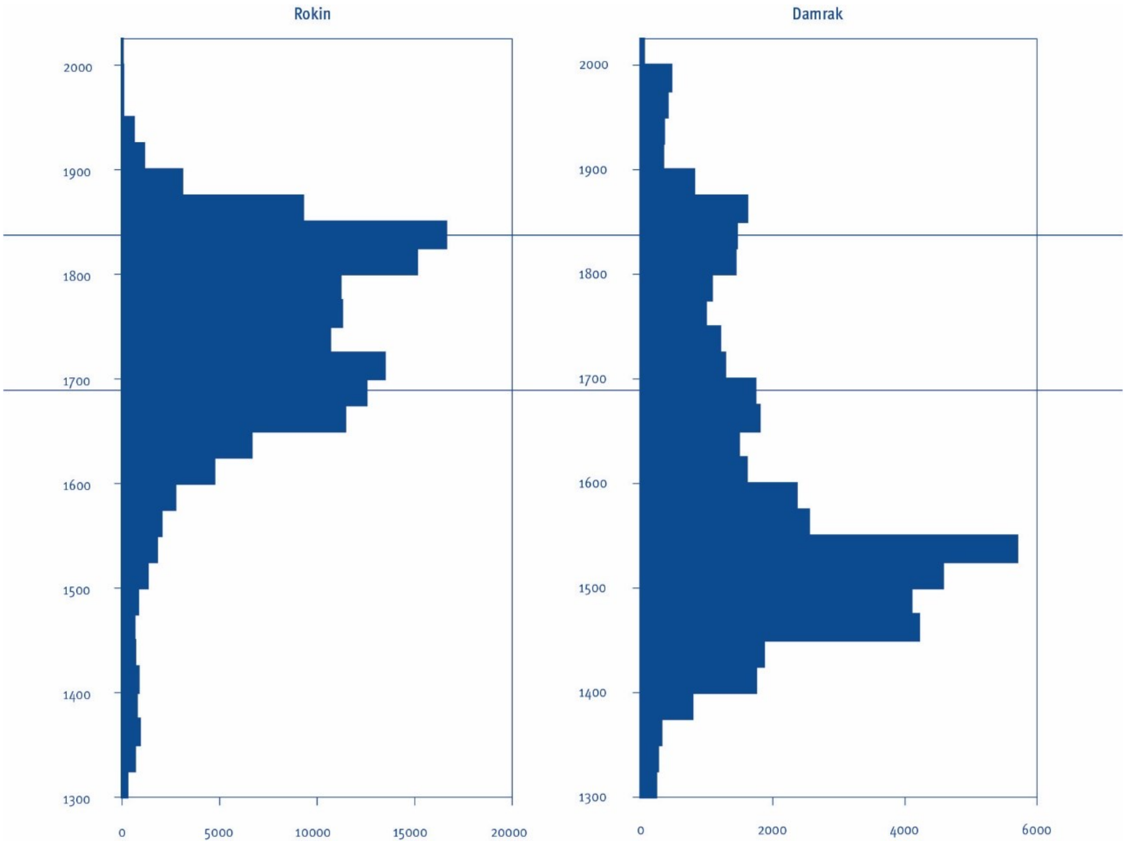
*Table 2. Distribution of the finds from Damrak and Rokin per material category (Gawronski et al. 2018, p. 22: design Willem van Zoetendaal)*

Regarding the dating of the finds, both sites share as a common feature a long term almost continuous chronology. As Rokin was filled in in 1937 and Damrak was still open water during the excavation in 2005, the finds from the river in its urban context at these two locations date not only from the medieval and early modern period, but are also related to the modern era, linking urban material culture from a historic context to the present day (Fig. 3).

*Fig. 3. Ceramics from Damrak and Rokin, dating from the 14th to the 20th century (photo: City of Amsterdam, Monuments and Archaeology)*

At the same time, the two sites show striking find dating differences. The chronological data shows that the bulk of the Damrak material dates from 1450 to 1600 (Graph 1).

The peak in the first half of the 16th century can be put down to the construction in the first quarter of that century of a land abutment for the 'Nieuwe Brug' (New Bridge), which was filled with urban waste. This bridge connected the eastern and western banks of the mouth of the Amstel at Damrak and was first mentioned in 1365 but was built at an earlier date (Gawronski, 2012, p. 30). Originally of wood, the bridge was fitted with stone arches around 1529 on the west side, keeping its span of wooden piers at the eastern end certainly until well into the 17th century. Another factor that affected the chronology of the finds is the construction of the massive wooden floor of the lock in 1681, sealing the streambed beneath the bridge. The Rokin finds, on the other hand, mainly date from the period 1650–1850. The more recent dating can be attributed largely to the dredging operations carried out from 1600 to maintain water levels for shipping, which cleared the waterways of material remains from earlier periods. Thus, the two sites give a further insight into the city's material culture in these eras. Despite their different dating, the two locations show the same pattern between 1600 and 1900, with a similar (slight) peak around 1650–1725 and 1800–1875. This dating pattern may well mirror major economic cycles, such as the blossoming of trade and the city in the 17th century, stagnation and decline in the 18th century, and the renewed opportunity and growth brought by the industrial revolution in the 19th century.




*Graph 1. Distribution in blocks of 25 years of the dated finds from Damrak and Rokin (Gawronski et al. 2018, p. 22: design Willem van Zoetendaal)*

## 3D GIS of the Rokin

In addition to numerical and statistical analyses, the spatial distribution of the finds provided further evidence for a reconstruction of activities at Damrak and Rokin and the functional significance of these locations within the city's topography. To focus on Rokin, in the processing of the finds from this site new techniques were used to transform the excavated riverbed into a source of urban histories. Software in the form of GIS (Geographic Information System) was used to develop a 3D GIS-model of the geological structure of the riverbed (Fig. 4). For this over one hundred cross-sections of the river, which had been mapped over the entire length of the excavation site, were digitised and combined. Two-dimensional data, such as historical maps and other digitised information, was also imported into this three-dimensional model. Even though the finds had no exact XYZ-coordinates, they could still be incorporated into the model using their position in the grid or soil layer. The integration of different data sets and map layers opened up new possibilities for working with complex archaeological and geological data.

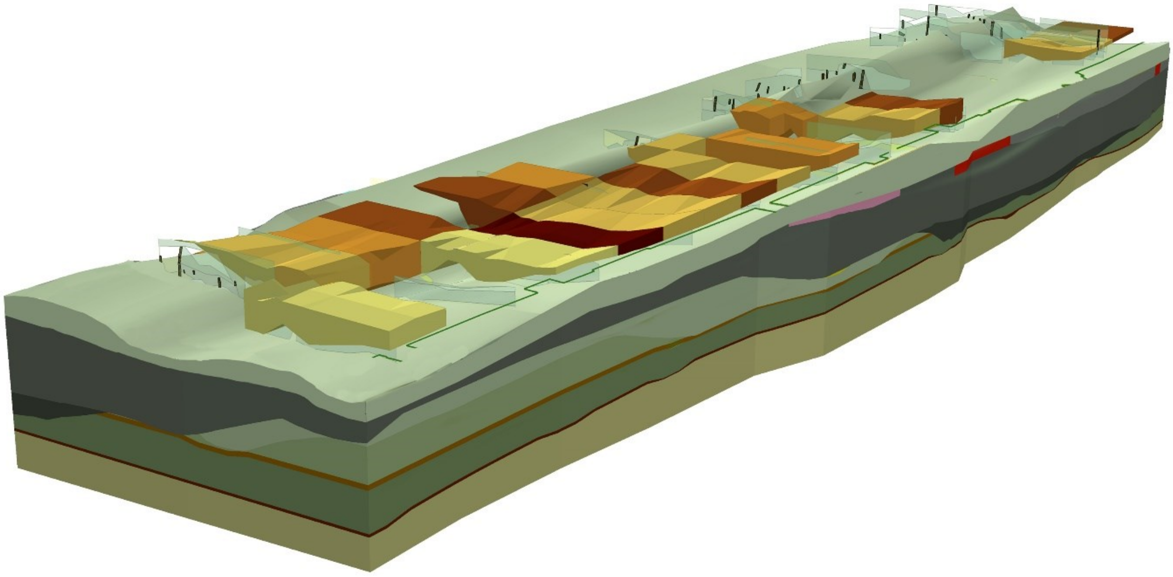


*Fig. 4. 3D GIS-model of the geological structure and archaeological content of the riverbed of the Amstel at Rokin (3D GIS: City of Amsterdam, Monuments and Archaeology; Jort Maas, Bart Vissers)*

In effect, the model turned the riverbed as a whole into a queryable database on the spatial distribution of the finds and their functional relations. With the 3D GIS-model it is possible to plot variation in find distributions using cartographic representations, and in this way document (changes in) the use of space along the riverbank. The similarities as well as the differences between the spatial find patterns can indicate that certain functional find groups correspond with certain activity areas, providing the basis for the reconstruction of a story about past urban life. A practical example of this theoretical distribution principle provides the different distribution of sherds of sugar funnels and syrup jugs, both of which were made of the same red earthenware (redware) but which were functionally different (Fig. 5). The funnels were exclusively used in the sugar refining process whereas the syrup jugs are thought to have been involved with distribution and consumption of syrup, a residual product of sugar fabrication from sugar molasses. This functional difference is reflected in their two different spatial concentration patterns, pointing to a possible association with activities in certain parcels along the river. In the case of the sugar funnels this pattern can be historically substantiated, for it can be traced back to the premises of the confectionery establishment ‘De Drie Suikerbroden’ (The Three Sugar Loaves) on parcels 87–89 along Rokin. The sugar factory was founded in 1611 by the Hamburg emigrant Hans Pelt and after extending the business to parcels 81–85 in 1651, he continued to operate under the name ‘De Vier Suikerbroden’ (The Four Sugar Loaves) until 1842 (Alings, 1964). Two and a half centuries later, the sugar funnel finds attest to the disposal of industrial waste right in front of the building on Rokin. This pattern clearly indicates that, despite soil disturbances that can be expected of an urban river, spatial relations between finds and activity areas can still be identified. The concentration of syrup jugs farther along the riverbank raises the question of whether this could point to a historically unknown sales or distribution point.

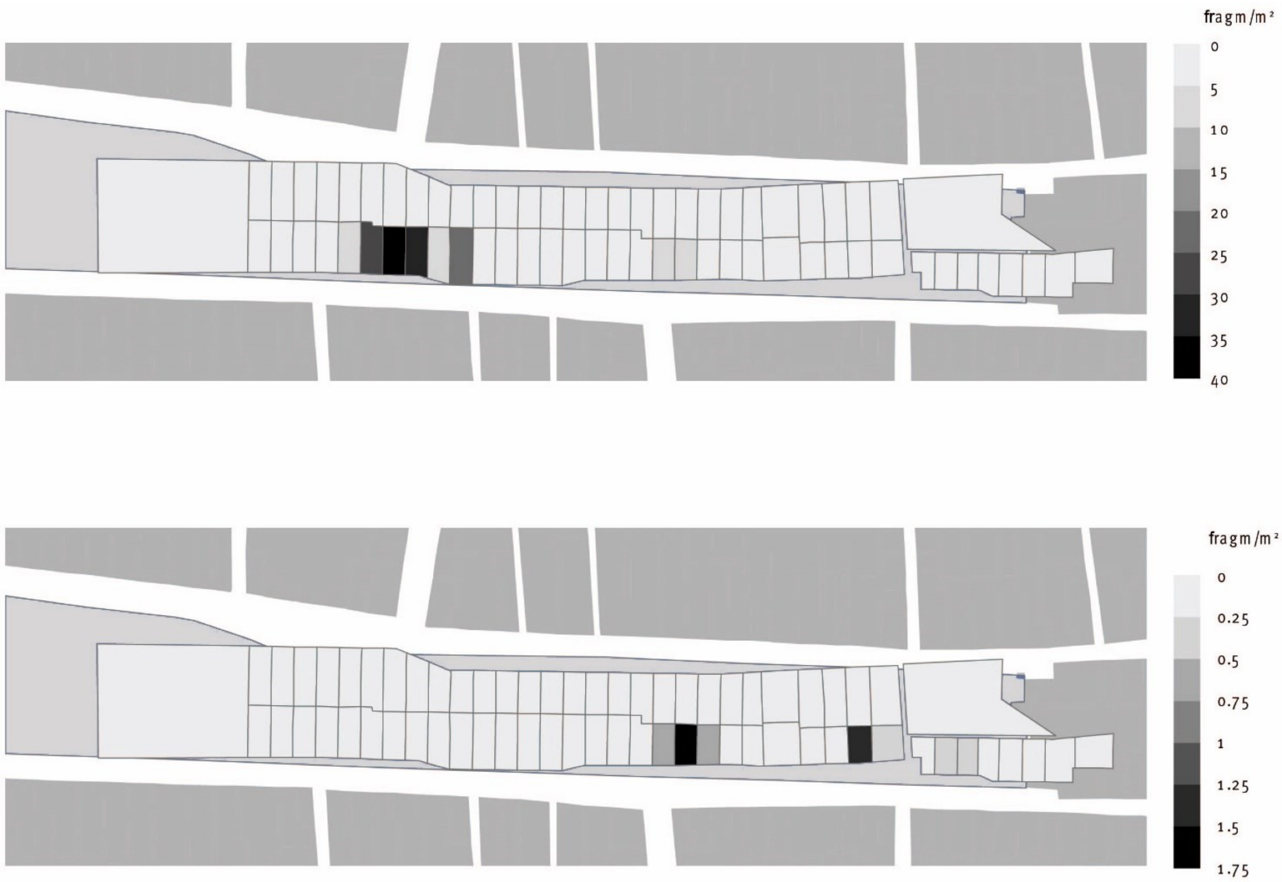



*Fig. 5. Distribution on the Rokin of sugar jars (top) (concentration in front of sugar factory) and syrup jugs (bottom) (map: City of Amsterdam, Monuments and Archaeology; Jort Maas, Bart Vissers)*

## Urban classification

In view of the great potential of the Damrak and Rokin finds for urban story-telling a classification scheme was developed through which the varied finds from the riverbed would reflect the city as an entity. As discussed, cataloguing of archaeological remains is based on the selection of one specific feature of a find from the database. Which criterion is selected and what meaning is given is for the archaeologist to decide. Ultimately, archaeological meaning is a subjective perception even though it is based on calculated and objective information. This applies even more so to an archaeological catalogue, since it entails by definition a selective arrangement of the finds. The central structure of a catalogue can only be based on one criterion or attribute at a time. Various catalogue systems exist. For instance, to convey an era, the objects can be presented chronologically, or, for a spatial presentation, arranged according to where they were produced or how they were distributed at the site. Archaeological catalogues tend to be functional overviews in which the objects are grouped according to their function or purpose, very often in conjunction with the material they are made of.

The ambition of the classification of the Damrak and Rokin finds was to turn the riverbed of the Amstel into a material mirror of the city, analogous to the river's water surface which reflects the city structures along its bank on a calm windless day. Therefore, a classification of material remains was developed around the functional, spatial, logistical, economic and cultural characteristics that typify an urban centre. A city sets itself apart from the country and non-urban communities in the scale and diversity with which these characteristics are given expression. A city such as Amsterdam can be broken down into ten main functional features which were added to the finds database for an urban ordering of the archaeological remains. This ordering structure is based on classifications used for large museum collections, and these in turn are based on the assumption that every artefact originally assumed a specific role and place in the interaction between man and his surroundings (Chenhall, 1988). Through their individual functional properties the objects can be allocated to one of ten main urban categories of the overall classification system. The ten urban categories are (Gawronski et al., 2018, pp. 27–28):

1. Buildings & structures: the city is a spatial phenomenon with a built environment that is shaped by the constructed amenities of urban life, such as city walls, churches, hospitals and theatres.
2. Interiors & accessories: the city provides a living environment which is reflected in the furnishings of interiors, including furniture and permanent fixtures.
3. Distribution & transport: the city functions as an infrastructural junction for the transportation of goods and people by water, land and air.
4. Craft & industry: the city is a centre of multifarious production with the capacity to upscale from an artisanal to an industrial level.
5. Food processing & consumption: the city is a subsistence environment where people provide for their daily needs themselves.
6. Science & technology: the city is a centre of knowledge serving the advancement of science and technology.
7. Arms & armour: the city provides citizens with a safe environment, generally in tandem with law enforcement and the use of arms.
8. Communication & exchange: the city is an environment conducive to the exchange of ideas, goods and news. This is what sets urban culture apart. Social and cultural processes in such diverse areas as information transfer, religion, art, monetary transactions and (product) quality guarantee fall into this category.
9. Games & recreation: the city is an environment where people relax and enjoy free time.
10. Personal artefacts & clothing: the city is a place made up of individuals with both a private life and a life as a member of the urban community. Anything that distinguishes a person as an individual, from prostheses to jewellery, falls into this category.

## Photo atlas *Stuff*

The urban classification system was used as the basis for different products to present the archaeological finds in varying settings and contexts. The first was a printed find catalogue, the more conventional spinoff of archaeological practice.

The find collection amounted to a total of 665,412 objects. In approximately 73 % of the finds (482,502 objects), the significance could be traced to a (pre-)urban context. Each prototype or each series of similar but individual objects among these finds are reproduced in this catalogue, titled *Stuff*, in 11,279 photographs (Gawronski et al., 2018). The challenge was to make the results of the archaeological excavations visually accessible. While the scientific ordering system supplied by the archaeologists was the starting point of the catalogue, the visual experience was realised by the layout of the designer and photographer. *Stuff* distinguishes itself from mainstream archaeological catalogues because of the close cooperation between archaeologist, photographer, designer and printer. A trustful cooperation in which each discipline had its own equal say resulted in a visual strong experience, telling a story of material sequences of urban life by serial images of finds.

At first glance, *Stuff* is a never-ending stream of different, more or less recognisable objects that invites us to browse and explore our own associations and reconstructions. But behind the cascading images lies an archaeological story that gradually emerges out of the visual structure, creating an atlas instead of a conventional catalogue, thanks to Willem van Zoetendaal's lucid and seductive design. The photographs tell their own story, prompted not by text but by their arrangement in chapters and sections according to the different functions that a city fulfils as a living organism. The material remains are primarily organised according to the role the object once assumed within these different urban functions. The finds derive their significance from the functional and chronological relation with the city assigned to them in the catalogue. Basic catalogue information, like find number, size and dating, was allocated to each find in a vertical bar left of the object photo, contributing to an object waterfall-like design grid which made this large quantity of visual information accessible (Fig. 6). Each singular image had a powerful visual effect because of the unmatched eye for detail, colour and texture of photographer Harold Strak, who documented more than 20,000 finds during the project. To underline the basic practice of archaeologists who by excavating do nothing less than reading the book of the earth, the printer (Rob Stolk, Amsterdam) used custom-made paper with a semi transparent effect, showing the contours of the finds on the next pages, simulating find layers in the underground.


*Fig. 6. Spread of two pages from chapter Communication and Exchange of photo atlas Stuff (Gawronski et al. 2018, pp. 422–423), with finds related to typographical work and telecommunication 1900–2005 (© Harold Strak)*

**Two showcases at Station Rokin**

Archaeology was part of the art programme of the North/South metro line project. Each station features artwork with a specific theme by different national and international artists. The theme of Station Rokin in the heart of the historic city was history and archaeology. The commission for the platform walls of this station was awarded to the British/French partnership Daniel Dewar & Grégory Gicquel. Using different kinds of stone, they constructed a monumental mosaic of 33 enlarged images of every day modern objects inspired by archaeological finds in two 110 m long strips, together representing a sentence telling a layered story. Their sentence was called *The crocodile, the melodica, the pike fish, the high heel pump, the sportswear shoe, the rear derailleur, the tie, the sandal, the ballpoint pen, the pipe, the shrimp, the garden tiger moth, the pair of dice, the leopard frog, the sewing machine, the Welsh Corgi Pembroke dog, the calico cat, the flat-twin car engine, the rattlesnake, the French horn, the teapot, the wetsuit, the handheld fan, the mallard, the diving flipper, the paintbrush, the nutcracker, the whelk shell, the fishing lure, the foxglove, the umbrella, the dragonfly, and the badminton racket*. In addition to the artwork on the platform, two permanent displays of authentic archaeological finds were incorporated in the architectural design of the metro station by Benthem Crouwel Architects. The archaeological team in cooperation with the artists were responsible for the content and production of these showcases which were situated between the escalators at the south and north entrances to the platforms. The basic principle of the public display was to show as much archaeological finds as possible to reflect the abundance of the material deposits in the river Amstel, while treating each object as autonomous with its own unique meaning, ordered in the non-hierarchical urban functional classification scheme. The two massive glass display cases - 12 m long and 3.34 m wide at the north entrance and 14 m long and 3.59 m wide at the south entrance, both tapering down to a width of 2.06 m—contain in total 9,500 archaeological finds selected from durable mainly inorganic materials (ceramics, glass, metal or bone) (Fig. 7). The objects are attached with thin brass pins to the sloping bottom of the showcases, which follow the incline of the escalator (a gradient of 30°), giving the impression of a free fall of material remains. As each display is categorized, a hidden visual order is created in the apparent chaos of objects which lack any written explanation. The north display shows the categories (from top to bottom) *food processing and consumption, science and technology, arms and armour, communication and exchange, games and recreation, personal artefacts and clothing* and the south display the themes *buildings and structures, interiors and accessories, distribution and transport, craft and industry*.

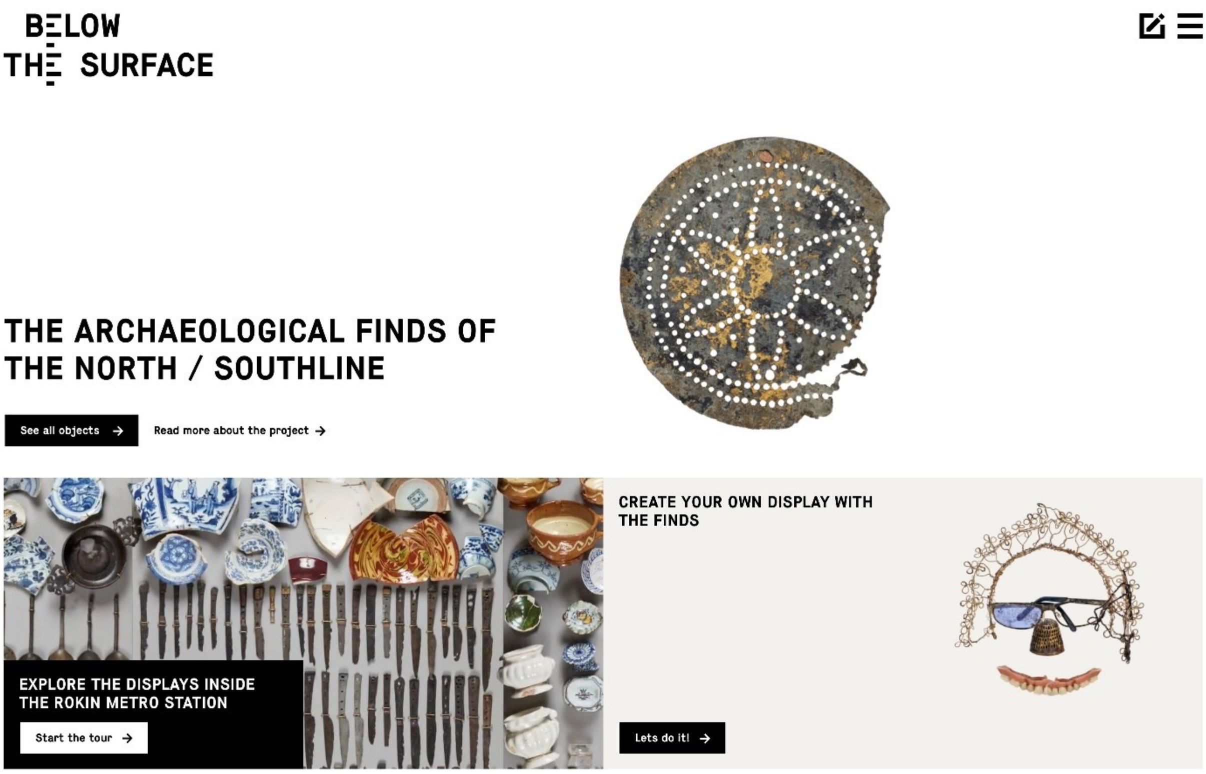



*Fig. 7. The showcase between the escalators at the north entrance (photo: City of Amsterdam, Monuments and Archaeology; Ranjith Jayasena)*

## Belowthesurface.amsterdam web portal

To accompany the two displays a multipurpose archaeological website[1] was developed by the Department of Archaeology and the CTO innovation team (Chief Technology Office) of the city of Amsterdam. Although the station is an accessible public museum, which can be visited for the price of a mere metro ticket, the displays lack background information on the finds. Unlike in a regular museum setting, visitors and travellers are unprepared for the archaeological experience and the objects flash past as the escalators do not stop. Belowthesurface provides digital access to both displays, which are rendered in the website as a GIS model which is linked to the database. In this way details of each of the 9,500 finds on display can be directly accessed, either in the station itself by smart phone or at home behind a computer (Fig. 8). The core of the website is a timeline database, invented and designed by Fabrique and programmed by Q42, which enables the visitor to scroll through the finds from 2005 to more then 100,000 years ago. Alongside the timeline finds can be searched by material, function or location. The website contains more than 27,000 photographs of 19,000 finds. To zoom in on the different finds on line, Q42 applied Micrio, a IIIF (I**nternational Image Interoperability Framework) compatible** platform (**image viewer and image server)** for telling visual, interactive stories with the highest resolution images. The site can be used for fun, and to do serious archaeological research as the complete dataset (135,000 records) of all (700,000) finds of the archaeological project is incorporated in B*elowthesurface.* The finds are not only

[1] https://belowthesurface.amsterdam

accessible in a passive way, but you can also create your own digital showcase of your favourite finds. Each find in the timeline database can be selected and added to a personal showcase which can be published online, on site. On Belowthesurface, archaeological finds can be used both as scientific datasets on our past and as visual elements in a creative display adventure. Different people from all over the world created their own showcases (3,050 by January 2020 since the launch of the website mid 2018) discovering a creative entry to science. As each element of the visual showcase composition stays linked to the archaeological database, Belowthesurface combines scientific curiosity with creative self-motivation, thus creating new ways to experience archaeology and the material past.

*Fig. 8. Homepage of the website Belowthesurface.amsterdam containing three different functions: timeline database of 19,000 finds, the two showcases at Station Rokin and creating your own showcase (source: https://belowthesurface.amsterdam)*

## Postscript

For each product a specific design format was developed and invented to create an inviting and understandable language to tell archaeological stories. In the end, archaeology is all about story telling about the past. More then written historical sources, the archaeological objects have a strong visual impact. To visualise the Amstel river artefact story, new and exciting design options have been explored beyond the classical archaeological cataloguing systems to render meaning to material culture. In this construction process the archaeologist had to work together with non scientific partners, like artists, photographers and designers. Combined with new and innovative (digital) technology, trust proofed to be the most vital and basic prerequisite for finding attractive ways to communicate with the public. By trusting the creative input of non archaeological partners, the archaeologist can avoid the straitjacket of traditional cataloguing and find new visual ordering for archaeological finds without nullifying or neglecting scientific standards.

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# Session:
# Major Projects and Digital Data

## The Present and the Future

Jay CARVER | Ann DEGRAEVE | Stephen STEAD

# Major Projects and Digital Data

## The Present and the Future

Chairs:
Jay CARVER, Independent, UK
Ann DEGRAEVE, Urban Brussels, Belgium
Stephen STEAD, Paveprime Ltd., UK

***Keywords**: Major projects—infrastructure—highways—rail—metro—power—ports—digital data capture—synthesis—dissemination*

Major infrastructure projects have the potential to create significant new knowledge in cultural heritage, especially in archaeological research. These projects are a real challenge for cultural heritage institutions that seek to document/preserve as much of the cultural heritage in the area considered. Ideally, cultural heritage institutions are involved in all phases of these projects including planning, implementing, and dissemination of the results in terms of new cultural heritage information. Due to their large scale and the often accompanying time pressure, the various tasks involving cultural heritage data management of large construction projects can drive innovation. In the planning phase, it is important to assess different alternatives based on known cultural heritage data. This assessment is often supplemented by commissioning prospection activities (e.g. geophysical survey) in areas where reliable data is not yet available. All cultural heritage sites destroyed in the course of a construction project must be adequately recorded before destruction. In this situation, cultural heritage institutions face new challenges such as excavations in tunnels, coordinating several excavation teams, dealing with sophisticated urban stratigraphy, large amounts of finds as well as large analogue and digital datasets. This session offered the opportunity to exchange ideas and experiences of practitioners and researchers who used new technologies to record as much as possible of the cultural heritage affected by large construction projects, how they were able to address regional/national research questions and how the knowledge production was re-invested into the existing cultural heritage data. The session organisers especially welcomed contributions that dealed with new technologies and data management in the course of the several phases of large construction projects.

# Scaling up to meet the demand

## Digital innovation within the UK's largest archaeological projects

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doi: 10.11588/propylaeum.747.

This paper will present innovations in digital data capture and management that have been brought about by the execution of two large linear infrastructure projects that are currently underway in the UK. It is meant as an honest and pragmatic contribution, being as much about innovation (major and minor) as the essential matter or applying and exploiting them in the context of these huge projects, and the success or otherwise achieved.

The first project is the building of a new road; the A14 Cambridge to Huntingdon Improvement Scheme (Fig. 1) in Eastern England. At some 23 km in length and comprising a total archaeologically excavated area of c.3.5 km dug by a team of 250 archaeologists (and a further 50 in support roles) over 18 months, this was one of the largest archaeological projects carried out in the UK in recent years.

The second project of interest, are the works in advance of the UKs new High Speed rail line (High Speed 2 [HS2] Phase 1 which runs due north from London to Birmingham 230 km).

The A14 project is now entering the post-excavation phase with site work now complete. Mitigation work on most HS2 phase 1 sites is yet to start, although there has been much excavation carried out on the two burial sites at either end of it (Fig. 2). The A14 project had been one of the largest archaeological projects ever undertaken in the UK; HS2 is an order of magnitude bigger.

There are a number of salient factors of such large-scale projects, primarily organizational and logistic in nature. These factors include the necessarily mixed nature of the archaeological workforce needed to execute such projects, and the need for formal joint ventures to ensure defense in depth and assuredness to the client that the work can be delivered.

As relevant are the increasingly specific requirements placed on archaeological contactors by the scheme owners, particularly with regard to matters such as the standing expectation to innovate, the desire to create less yet more targeted information and the exhortation to produce long term community benefit. Specifically, the General Written Scheme of Investigation for Historic Environment Research and Delivery Strategy for HS2 phase 1 (HS2 Ltd 2017) can be cited, which itself

[1] Museum Of London Archaeology Service

implements much of the ethos defined in the Social Value Act 2013 (UK Government, 2013). Four examples of innovation will then be discussed.

*Fig. 1. Circular 'henge' monument thought to have been used as a ceremonial space (© Highways England) courtesy of MOLA Headland Infrastructure*

## Innovation in aerial survey

Aerial survey proved incredibly useful in maintaining control and providing context to a developing Project (Fig. 2), with multiple simultaneous excavation totaling c. 3.5 km$^2$. Planned enhancements to aerial operations include enhancing situational awareness, via live streams from the aircraft to remote persons responsible for monitoring progress and signing off areas, and the increasing affordable application of UAV bourne LiDAR. The *habitual* embedding of UAV bourne multi-spectral imaging into the evaluation phases of large mainstream infrastructure is also underway.

## Collaborative Data Environments

The creation of web hosted archaeological collaborative data environment, (CDE) also proved invaluable on project in which different geographical dispersed organizations (constituted as joint-ventures which clients encouraged given the scale of works undertaken) and teams of lone specialists, all had to communicate effectively and record data to the same standard. Oracle based Infrastructure As A Service (IAAS) offerings, specifically DBAAS2 and Cloud Compute3 (Oracle, 2019) platforms were utilized. A number of factors proved pertinent; the need to re-engineer on-site based workflows, the never-ending importance of training, and the practical matter of providing remote support to a dispersed team

## Asset tracking

Following problems encountered in keeping track of thousands of environmental samples, and an initial attempt to extend database structures within the archaeological CDE to mitigate this, the problem was recast as simply one of logistics. This notion presaged the adoption of commercial asset tracking system with only slight adaptions being made to the archaeological data tables to enable the minimal level of communication required.

*Fig. 2. Archaeologists excavating the St James Burial ground for HS2 (© HS2) courtesy of MOLA Headland Infrastructure.*

## Supporting assessments

Finally, these projects engendered improvements in the transition from the excavation into the post excavation and analysis phases, enabling the completion of a valid, and research-goal targeted assessment of the material's analytical potential to be made.

The need was to rapidly characterize the sites based on the *coarse,* yet abundant data captured during the excavation phase. Reporting routines based on eth CDE data sets had to evolve to enable statements to be made about both the broad dates of material and the key landscape features present on a site, with which object specialists could better assess the significance of their assemblage.

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# Data Structures for Major Archaeological Projects in the Rhineland Area, Germany

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***Keywords:*** *Large excavations—Databases—GIS—Document repository*

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## Introduction

National or regional archaeological databases have a long tradition in digital cultural heritage management. For instance, the book edited by Larsen in 1992 provides information on such databases in nine different countries, including the database in the Rhineland Commission for Archaeological Sites and Monuments (abbreviation in German: ABR) in Bonn, Germany (Scollar, 1992). As in most countries, the software for this database has been updated several times since 1992, and this information system nowadays includes a powerful GIS component as well as a document management system (Herzog et al., 2015; Herzog, 2018). An important component of this system called BODEON is the management of planning projects, and this paper will focus on this unique component.

The main aim of the ABR is the protection and research of archaeological and palaeontological monuments in a densely populated area covering more than 12,000 km² (Fig. 1). For each planning project in the Rhineland (excluding the city of Cologne), the ABR analyses the probability of archaeological remains in the affected area based on previous archaeological investigations recorded in BODEON. Another source of information are the web map services (WMS) provided by the local ordnance survey institution (Geobasis NRW). Moreover, it is important to check the statements by the ABR concerning previous projects covering the same area. This saves time and ensures consistency. These statements are recorded in the planning project component of BODEON. In negotiations with the ABR, an investor may decide to commission a rescue excavation, the main data of which will be imported in BODEON, forming not only a basis for assessing future planning projects, but also for research. This paper will describe the digital management of planning projects that affect archaeological remains using an example from the city of Bonn.

However, BODEON is not only important for managing major projects but has also become an indispensable tool for nearly all archaeology related office work in the ABR. This is illustrated by the amount of new data records entered in the years 2017 and 2018 (Table 1).

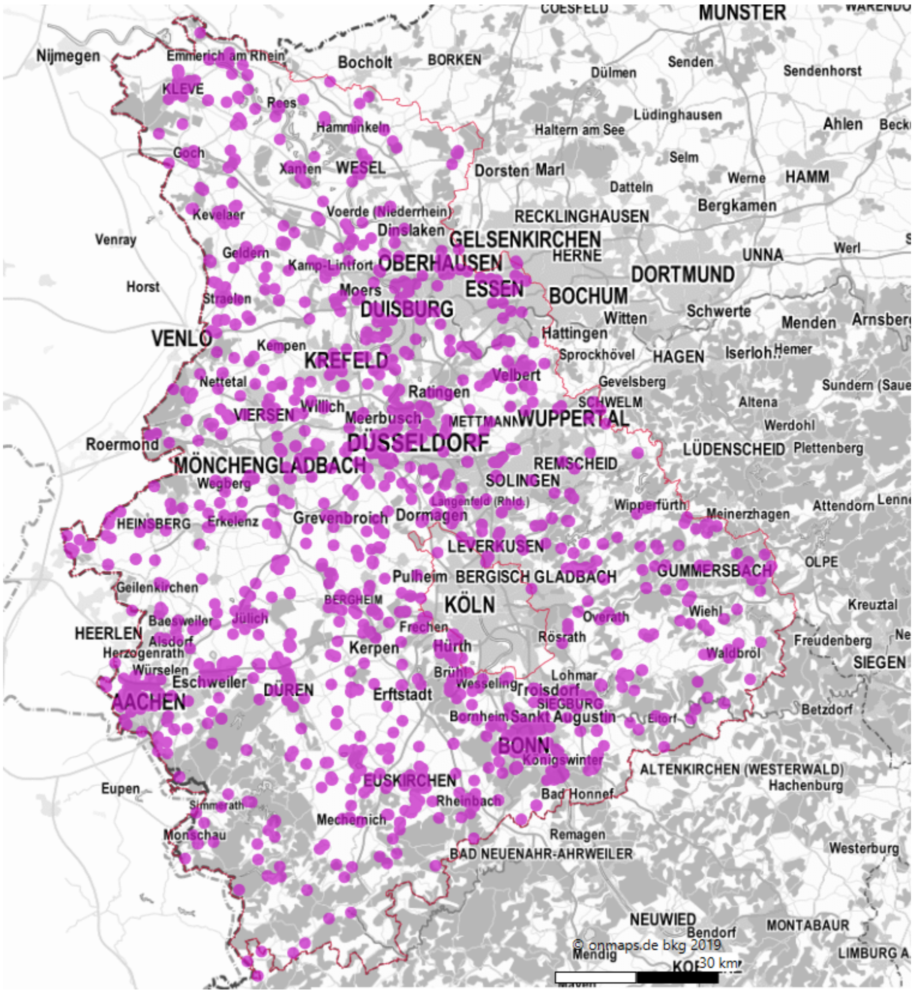


*Fig. 1. BODEON screenshot: New planning projects in 2018 recorded for the Rhineland (© Irmela Herzog)*

| Data base record type | New in 2017 | New in 2018 |
|---|---|---|
| Request for assessing the archaeological potential of a spatial planning area (mostly concerning infrastructure projects of varying sizes) | 1855 | 1666 |
| Processing step for a spatial planning area classified as outgoing mail | 4269 | 3428 |
| Rescue excavation initiated due to a planning process | 354 | 331 |
| Archaeological feature recorded during a rescue excavation | 22,901 | 22,208 |
| Photograph (+ meta data) taken in the course of a rescue excavation | 42,765 | 23,407 |
| Archaeological investigation not classified as rescue excavation | 1738 | 1317 |

*Table 1. Number of new BODEON entries in 2017 and 2018 for several data categories*

## Data management

When receiving a new request for assessing the archaeological potential of a spatial planning area, a new database record is entered in the planning project component of BODEON. This record includes the boundaries of the affected area, which are imported or digitized from paper maps using the tools of the GIS component. Moreover, for each of the planning records, the corresponding processing steps are entered in the database. Typically, a new processing step is created when sending or receiving a mail dealing with a planning area. Both the mail texts and any attachments are stored in the document management system (https://mediafiler.com/en) seamlessly integrated in BODEON.

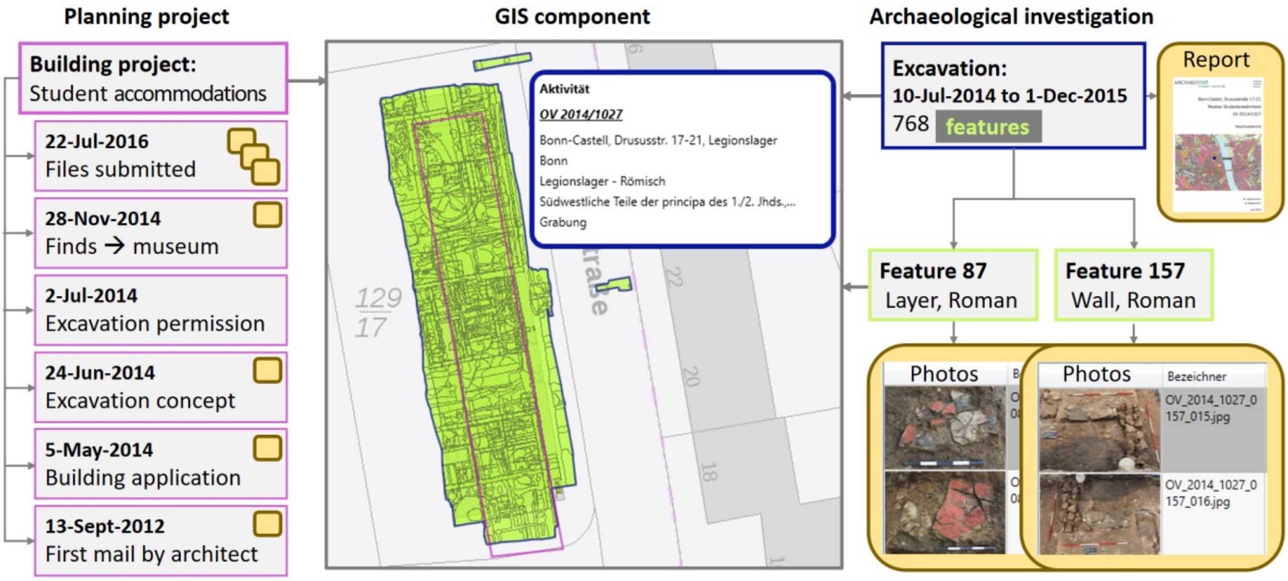


*Fig. 2. BODEON: Simplified data structures and relationships illustrated by an example from Bonn (© Irmela Herzog)*

Fig. 2 illustrates the data structures implemented in BODEON, taking the planning project for student accommodations in the city of Bonn as an example. Only selected processing steps of the planning project are shown. The planning project data base entry was created after receiving an architect's mail requesting information on the archaeological remains in this area. Later, the investor has initiated a rescue excavation, during which 768 features were documented. The BODEON data structures for the excavation data are outlined in the right part of Fig. 2. Rounded rectangles with yellow background indicate documents that are linked to the corresponding data base records. Any number of documents can be linked to a processing step, an archaeological investigation, an archaeological feature or an artefact record in BODEON. Planning projects, archaeological investigations and the features detected during such investigations use the same GIS component and a common data structure for recording location information.

## GIS component

The central part of Fig. 2 is a screen shot from a BODEON map showing the pink spatial planning area. In the course of the planning project, several versions of the planning area may be under consideration, all versions can be stored in the database; by default, the most recent plan is displayed. Typical GIS tools such as measuring, subtracting areas, info-tool, moving or deleting nodes are supported. Moreover, BODEON automatically derives data from any map object entered, including the corresponding parish(es) and bounding box coordinates. Geobasis NRW provides WMS layers not only for topographic maps on different scales but also for three sets of rectified historical maps, aerial images (most recent; 1988–1994), and hill-shading of Lidar data (resolution 1 m), that can be invoked by merely two mouse clicks. A lookup table stores the links for additional WMS layers used less frequently such as colour infrared aerial images. The boundaries of parcels or buildings shown in the cadastral map layer can be copied easily for any BODEON object. The goto tool supports navigation to a user-supplied address or cadastral parcel number.

At the start of the excavation, a point object indicates the location of the excavation area. After the contract archaeologists submitted the files to the ABR, the boundaries of the excavation area and all features are imported as well as the corresponding metadata.

In Fig. 2, the mouse cursor was positioned on the excavation area when the screen image was captured, therefore selected metadata of the excavation is displayed in a rounded rectangle. In the excavation recording system used in the Rhineland, the term feature may refer to subdivisions of the excavation area as well as to archaeological features. This is why the features cover the complete excavation area in Fig. 2.

## New Version and Future Perspectives

BODEON started as a Windows program based on the plug-in Silverlight. As Microsoft ends the support for Silverlight in October 2021, BODEON was recently converted to a desktop program that can be started by an exe file. The internet is only used for transferring the data. Due to Rhineland specific WMS layers, language and licensing issues, the effort for adjusting this software for other archaeological institutions is not to be underestimated. However, developers of comparable information systems might be interested in setting up similar data structures for managing the archaeological aspects of planning projects.

Currently, planners do not have access to BODEON. Archaeological expertise is required to assess the potential and limits of the archaeological data recorded in BODEON, with the first find reports going back well beyond 1800. Contract archaeologists often prepare their excavation projects by visiting the filing department of the ABR, where they can use a BODEON PC. Due to data protection issues, such users do not get permission to inspect the documents associated with planning projects. In the medium term, it is the aim of the ABR that contract archaeologists enter their own rescue excavation data.

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# The Archive arriving on Platform 1….

## Digital Archives and Mega-infrastructure projects

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## Introduction

Major infrastructure projects offer special challenges and opportunities for digital preservation and access. On the one hand, they create digital data in unprecedented quantities, frequently combined with the use of project-specific recording systems, and an appetite for innovative digital methods. On the other hand, given the scale of the archaeological fieldwork, conventional publication is never an option, providing an incentive to investigate hybrid dissemination strategies, making the most of opportunities provided by digital media, as recommended as early as 2003 by the Council for British Archaeology's *Publication User Needs Survey* (Jones et al., 2003). Major infrastructure projects should also have the resources, and the incentives, to provide exemplars of the creative combination of digital and traditional publication methods.

The Archaeology Data Service (ADS) has provided digital preservation and dissemination for major transport infrastructure projects since 2004, and this paper will explore some of the challenges and opportunities we have encountered. It will draw upon our experience archiving the digital outputs of projects as diverse as Stansted Airport[1], Heathrow Terminal 5[2], the A1 and A14 trunk roads, the Channel Tunnel Rail Link[3], Crossrail, and most recently, HighSpeed2 (HS2).

Together these projects represent the largest transport infrastructure projects undertaken in the UK in the last 20 years. They comprise massive financial investments, usually with direct government funding, and the archaeological fieldwork generally represents a minute fraction of their budgets, within which the digital archiving is an even smaller proportion. Unlike smaller projects, therefore, the digital archiving is generally a negligible outlay compared with the overall costs of the

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[1] Framework Archaeology (2009) *The Stansted Framework Project*. doi: 10.5284/1000029.
[2] Framework Archaeology (2011) *Framework Archaeology Heathrow Terminal 5 Excavation Archive*. doi: 10.5284/1011888.
[3] Stuart Foreman (2018) *Channel Tunnel Rail Link Section 1*. doi: 10.5284/1000230.

programme. At the same time such projects may operate under some sort of “best value” framework, seeking to ensure cost-effective expenditure for the taxpayer, whilst maintaining or enhancing best practice (Andrews et al., 2000). For the archivists the scale of the archives presents major challenges in providing intuitive user interfaces and access to specific files.

## Opportunities

Ideally, large infrastructure projects should provide opportunities for early planning, assessing the archaeological work required (Carver, 2013), as well as the scale of data that will be generated and the solutions needed. Traditionally, archiving has often been regarded as an afterthought, following publication. With the advent of digital means of dissemination, however, access to online data should be seen as part of the overall publication strategy and planned from the outset. Similarly, the archiving strategy needs to be considered even before work starts on site, with guidelines on file formats, file naming conventions, and version control. For HS2, ADS prepared a digital archiving strategy whilst work was still in the planning stage (ADS, 2015). It may even be possible to embed digital archivists within contractors, ensuring best practice.

## Challenges

This is not always the case, however. In the rush to stay ahead of the bulldozer and under major time pressures there are occasions when the immediate priorities become the focus, shelving longer term archive preparation, and storing up problems for later. Archiving is once more relegated to an afterthought. There can be other challenges too. Large infrastructure projects may involve extended communication channels. At Stansted and Heathrow Terminal 5 the scale of the contract led to the establishment of a new super unit, Framework Archaeology, an over-arching consortium of Wessex and Oxford Archaeology. In recent rail infrastructure projects groups of archaeological contractors have worked with civil engineering consortia, and there are also archaeological consultants, hired direct by the “developer”, who manage the archaeological work. This can lead to delays and miscommunications between those providing guidance on data standards and those implementing them in the trench. In addition, it is normal for the primary contractors—the civil engineering consortia—to have their own proprietary IT systems, to which the archaeologists must adapt. In recent years these are generally based on BIM (Building Information Modelling) rather than the more usual GIS (Geographical Information Systems) with which most archaeologists are more familiar. This can create further difficulties for extracting the data in open formats. Furthermore, infrastructure projects are often politically sensitive and archaeologists, appearing in advance of the bulldozers, may have to operate in a climate of secrecy. Finally, the release of data may be subject to issues of client confidentially, running contrary to principles of Open Data.

## Conclusions

In summary, major infrastructure projects can offer exciting opportunities to provide wide public access to archaeology. Such benefits are often appreciated by developers, and free online access to heritage information can be used to counter the bad publicity that may surround these projects. For researchers there are also tremendous potential benefits of access to large data sets, enabling major works of synthesis, underpinned by reliable data collected to a consistent standard. If the challenges can be overcome, we can safeguard the legacy of these major archaeological investments and provide unparalleled research resources for the future.

*Fig. 1. Image from Framework Archaeology Stansted Airport digital archive.*

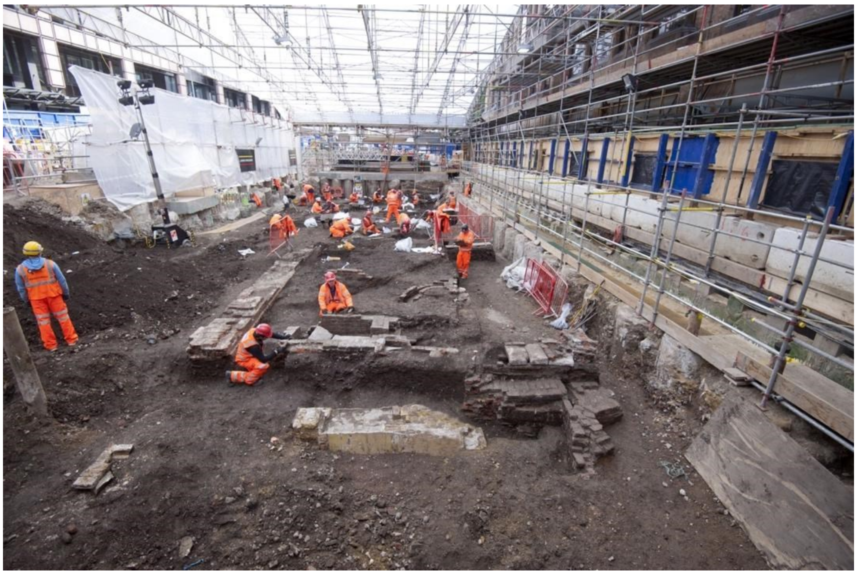

*Fig. 2. Image from the ADS Crossrail digital archive – excavations at Liverpool Street station.*

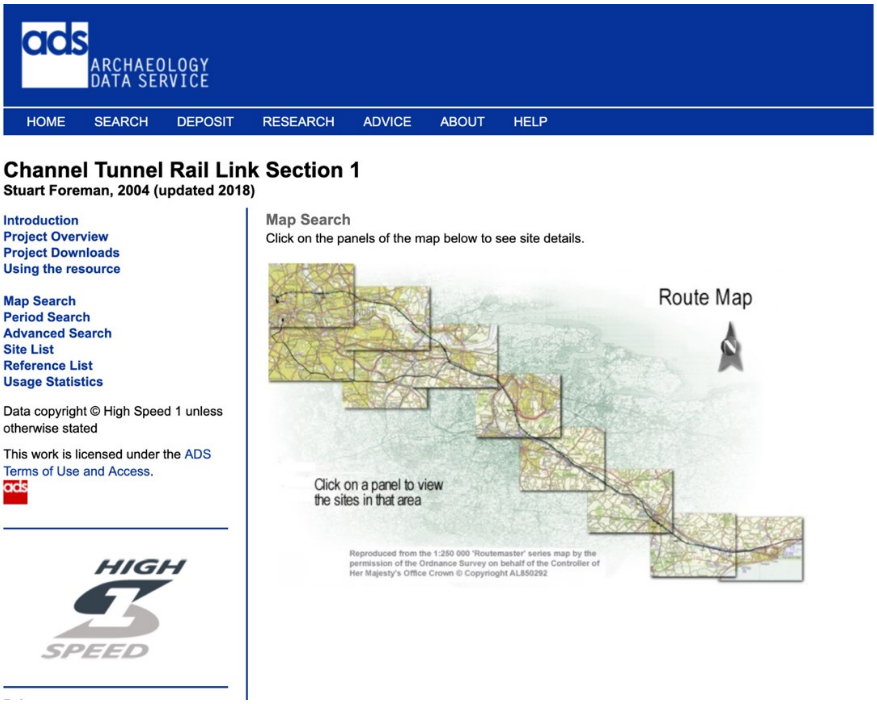


*Fig. 3. Landing page for the ADS Channel Tunnel Rail Link Digital Archive*. *doi: 10.5284/1000230.*

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# Session:
# Image-based 3D documentation aerial and underwater

## Photogrammetry, Georeferencing, Monitoring and Surveying

Marco BLOCK-BERLITZ | Martin OCZIPKA

# Image-based 3D documentation aerial and underwater

## Photogrammetry, Georeferencing, Monitoring and Surveying

Chairs:
Marco BLOCK-BERLITZ, HTW Dresden, Germany
Martin OCZIPKA, HTW Dresden, Germany

***Keywords**: image-based 3D reconstruction—photogrammetry—sfm—aerial—maritime*

Image-based 3D reconstruction is one of the standard tools used in archaeological excavations above and under water. Nevertheless, standardised workflows and recommendations for coping with and storing the enormous data are largely lacking. Especially in the field of underwater archaeology, practical solutions for reliable georeferencing are sought.

In this session we talked about practical solutions and showed current tools in the field of image-based 3D reconstruction.

Focussing on key aspects of managing surveys, this session invited papers dealing with topics such as:

- complete workflows and case-studies
- decision/planning support processes for excavation campaigns
- camera and lighting solutions for underwater archaeology
- monitoring: continuous excavation and site recording for
- conservation and long-term studies
- and data management solutions for recorded data and
- long-term accessibility of 3D data.

Contributions and perspectives are welcome, and may include the topics listed above or further improve established practise and processes.

# Resurrection of the Steppe Empires: Data Recording, Reconstruction and Semi-Automated Interpretation

## Application and development of advanced visualisation and edge detection methods in the context of the Uyghur capital of the 9th century

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**Abstract:** With the focus on segmentation for the identification of archaeological structures, 42 km² of elevation data is used. As a standard tool of archaeological documentation, the combination of UAVs and photogrammetry has been applied. The result of this investigation shall be an automatically generated city map from digital elevation data. The raw DEMs contain a lot of artefacts, which sometimes make interpretation challenging. Preparations were made to continue working with the corrected information. After the interpolation, scaling and georeferencing of geodata the actual processing could start. There are several visualisation techniques for digital elevation models. Hillshading, trend removal, sky view factor and topographic openness were tested. Each of the techniques has its own characteristics, but also limits. In order to use these techniques correctly, the results must be compared, to know which landscape suits which technique. To make the images more understandable, visualisation from remote sensing and methods from computer science were used together to enhance the visibility of certain landscape properties. Image preprocessing steps like edge detection, morphological operations or histogram stretching are required to display features more clearly. The combination of several technologies makes it possible to see different topographical features in one image. Although data processing and analysis is still in progress as the team experiments with different methods, first results demonstrate the capabilities of UAV-based mapping even at the scale of larger landscapes.

***Keywords:*** *3D reconstruction—photogrammetry—image processing—steppe empires—urban archaeology—remote sensing*

**CHNT Reference:** Do Duc, Huy; Block-Berlitz, Marco; Rohland, Hendrik; Franken, Christina; Batbayar, Tumurochir, and Erdenebat, Ulambayar. 2021. Resurrection of the Steppe Empires: Data Recording, Reconstruction and Semi-Automated Interpretation. Application and development of advanced visualisation and edge detection methods in the context of the Uyghur capital of the 9th century. Börner, Wolfgang; Kral-Börner, Christina, and Rohland, Hendrik (eds.), Monumental Computations: Digital Archaeology of Large Urban and Underground Infrastructures. Proceedings of the 24th International Conference on Cultural Heritage and New Technologies, held in Vienna, Austria, November 2019. Heidelberg: Propylaeum.
doi: 10.11588/propylaeum.747.

## Motivation and Introduction

The nomadic empires of Central Asia are particularly interesting phenomena in the history of the ancient civilisation. Despite the relatively small population and economy of the Eurasian steppes, they had huge impact on the course of human history. While these empires relied on the military strength and mobility of a mainly nomadic population, they time and again developed significant urban structures. For about twenty years, the German Archaeological Institute, the Mongolian Academy of Sciences and the National University of Ulaanbaatar have been jointly researching nomadic settlement structures, their characteristics and intercultural influences in the Mongolian Orkhon Valley.

Between 745 and 840, the nomadic tribe of the Turkic Uyghurs formed an empire in the Mongolian steppe. The Uyghur state stretched from Manchuria to Dzungaria and the Tarim Basin. They were military allies of the Chinese Tang dynasty. The military support of the Uyghurs was so crucial for the Chinese dynasty, that they had to grant favourable trading conditions and send presents and payments that numbered hundreds of thousands of pieces of silk a year (Mackerras, 1968). This wealth put the Uyghurs in a position to participate in the trade of the silk roads. They relied on Iranian Sogdians from Central Asia as traders and as advisors and administrators of their Empire (Golden 1992, pp. 172f). To facilitate trade, diplomacy and handicraft, the Uyghurs founded urban settlements (Fig. 1). Most prominent amongst them was their capital city, Qara Balğasun, which was situated in the "Ötükän" at the river Orkhon, in the sacred lands of the ancient Turkic royal ideology (Rosthorn, 1921; Gabain, 1950, pp. 33–35). The Arabian traveller Tamīm ibn Baḥr reported "[…] that this is a great town, rich in agriculture and surrounded by *rustāqs* full of cultivation and villages lying close together. The town has twelve iron gates of huge size. The town is populous and thickly crowded and has markets and various trades […]" (Minorsky, 1948, pp. 283). In 840 the city was destroyed by the invading Turkic tribe of the Kirgiz from the Upper Yenisei area. Upon the destruction of Qara Balğasun the Uyghur Empire also fell.

Only 30 km south from the ruins of the Uyghur metropolis, the Mongols founded Qara Qorum as capital of their emerging empire. Consequently, almost 400 years after the perishing of Qara Balğasun and the Uyghur Empire, the Orkhon Valley again became the centre of a steppe polity. Some sources claim that Genghis Khan himself chose the location of the city in 1220. In 1235 a city wall, a palace and a temple were erected. Further information on this city is provided through the reports of travellers and chroniclers from different cultures. Qara Qorum was a cosmopolitical centre, frequented by diplomats, noblemen, traders, missionaries and artisans from China, Central Asia, the Middle and Near East and even from Western Europe. Qara Qorum's zenith lasted until 1260, when Qubilai Khan usurped the throne of the empire and established his residences at Shangdu and Dadu (Peking) (Sagaster, 1999; Hüttel, 2005; Franken, 2015). Because of the historical significance of the ancient sites in the Orkhon Valley, UNESCO listed the whole region as a World Heritage Site in 2004.

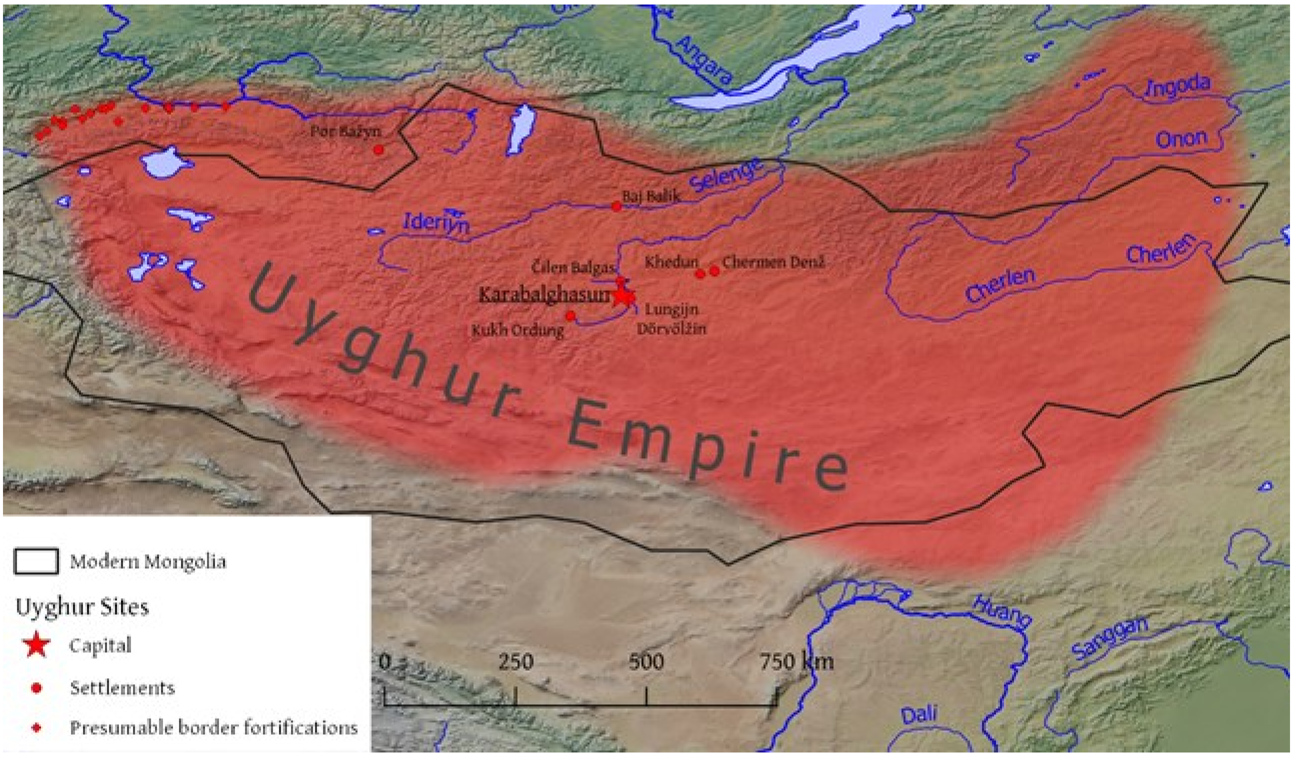



*Fig. 1. The Uyghur Empire and its settlements and fortresses in the 8th to 9th centuries. (Mapping: H. Rohland after Dähne 2017, Basemap: Natural Earth, Naturalearthdata.com) (© DAI)*

Despite basic information gained from historical sources, the history, structure and functions of the steppe capitals are, to a large extent, still a mystery. Excavations have been focused on monumental architecture such as palaces and temples, while the research on the overall structure of the cities and their hinterlands is still in its infancy. To address this issue, Mongolian-German joint research projects started with surveys and excavations in Karakorum in 2000, and in Qara Balğasun in 2007 (Hüttel/Erdenebat, 2010; Bemmann et. al., 2010; Franken et. al., 2014; 2017; Dähne, 2017). Detailed plans of the ancient remains on the surface are a crucial prerequisite for further research and understanding of the steppe cities. A Digital Surface Model has already been acquired for Qara Qorum by geodetic survey with a total station, painstakingly measuring over 80,000 points. The much bigger site of Qara Balğasun was surveyed with Airborne LiDaR by helicopter in 2007 (Hüttel, 2010). The results were amazing. The steppe provides almost perfect conditions for remote sensing techniques, due to its sparse vegetation and settlement (Fig. 2). However, LiDaR and pedestrian geodetic surveys are costly and therefore the surveyed areas were limited. Since the research on urban sites in the steppe is more and more interested in questions concerning the urban hinterland, urban sprawl and wider-ranging settlement patterns (Honeychurch and Amartuvshin, 2007; Waugh, 2010; Bemmann et. al., 2014), high-resolution mappings of huge areas are necessary. This poses the challenge to survey large areas in a short period of time with affordable equipment and to process the gathered data for scientific analysis.

*Fig. 2. The remains of the Uyghur capital Ordu-Baliq, also called Qara Balğasun, in the mongolian steppe. The overview taken in the evening with low sunlight illustrates, that the conditions are almost perfect for photogrammetric approaches for the creation of DEMs (Digital Elevation Models) (© DAI/archaeocopter).*

## Data acquisition and 3D reconstruction

UAVs in combination with methods of photogrammetry have established themselves as a standard tool of archaeological documentation. Multicopters with good cameras are becoming safer and cheaper nowadays.

### Recording strategy

In the Mongolian steppe, 42 $km^2$ were to be recorded in less than a week using standard multicopters. Two Phantom 4 were used for this purpose, each recording 526 m×526 m in parallel at a flight altitude of 100 metres. In this way, 4 flights covered 1.1 $km^2$ in just under 30 minutes (see Fig. 3).

### Preparation of data

For the processing of the huge number of images different approaches where tested. DroneDeploy, a web service for UAV based mapping, offers a free trial version, which was used to assess the capabilities of this provider. The imagery was processed into 2.5D color scale representations of the terrain and also into point clouds. The best way to find structures is to create a contour map. In most cases of image processing, the image has to be converted to greyscale first. Unfortunately, the coloured elevation models from DroneDeploy were not usable for greyscaling. For example, the yellow to green areas turned out to be more difficult to interpret and some of the elevation models were incomplete, containing blank areas. Another issue was that the files were not correctly displayed in geographical information systems like QGIS.

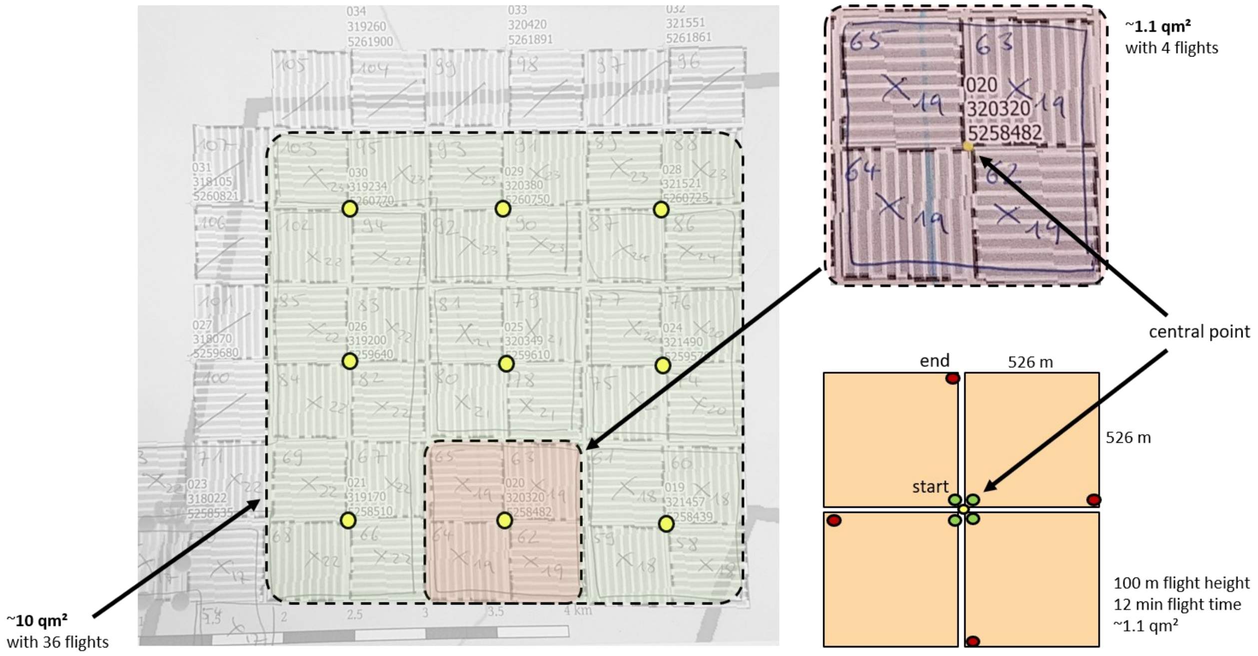



*Fig. 3. Four flight areas with a common starting point were chosen and recorded in parallel with two copters each. (© Marco Block-Berlitz)*

The solution to these problems was using the point clouds for the identification of structures, while the elevation models from DroneDeploy were essential for georeferencing. In addition to the elevation models, point clouds were exported as obj-File. The obj.-Files contain information of x,y coordinates with the z-values representing the elevation information. The first step was to interpolate the point clouds to elevation models. Interpolation is a way to estimate new points within a discrete number of known data points. In QGIS several methods are available and easy to use, for instance nearest neighbour, thin plate spline or inverse distance weighted. Accuracy of the elevation map borders are important when combining all raster data. The second step was to georeference the single maps.

For georeferencing two methods were tested. The first method was using QGIS and the plugin Georeferencer. To use this method, a reference map is necessary. Ground control points must be selected visually to match two maps. The disadvantage with this method is that every map must be georeferenced individually. The second method was using the georeferencing information of the exported elevation models from DroneDeploy. With the usage of the GDAL-library it was possible to extract the information on coordinate systems from the 2.5D images and apply it on the new interpolated elevation model. Most of the interpolated DEMs or raster data was not in the same resolution as the data from DroneDeploy. To apply the georeferencing information on interpolated point clouds, the raster data had to be resampled and resized.

## Visualisation Techniques for DEMs

After the processing of interpolation, scaling and georeferencing the actual image processing could start. There are several visualisation techniques for DEMs. Each of the techniques has its own characteristics, but also limits. In order to use these techniques correctly the results have to be compared to establish which technique suits which kind of landscape. To make the images more understandable, visualisations from remote sensing and methods from computer science were used together to enhance the visibility of certain landscape properties. Hillshading, trend removal, sky view factor and topographic openness were tested and analysed. For the visualisation QGIS and SAGA-GIS were used. SAGA-GIS is an open software project, which focuses on geographic raster data analysis.

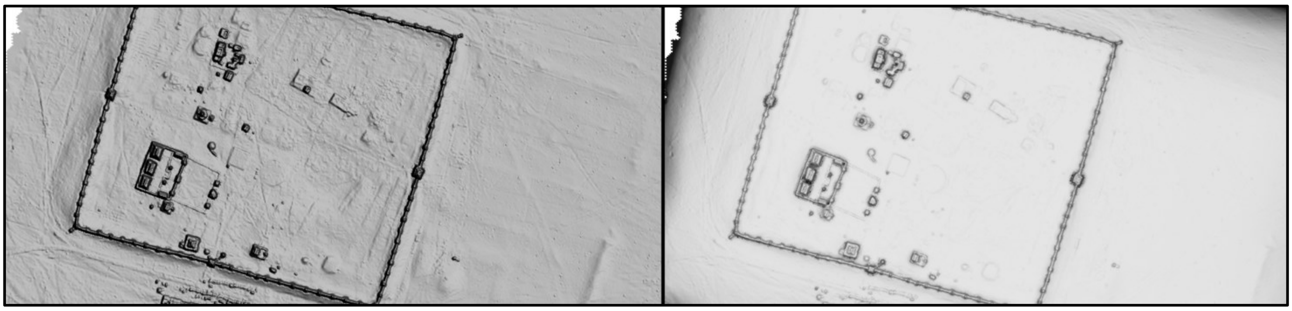


*Fig. 4. Left: With low computational power hillshading produces understandable results. Small elevations are also visible. One issue is that only one side of the structure is dominant. Right: SVF presents mostly big building and elevations. Small archaeological features are hardly visible. (© DAI/Huy Do Duc).*

### Analytical Hillshading

Hillshading is well-known and easy to work with. It relies on the basic assumption that the relief is a surface illuminated by direct light from a fictive light source at an infinitive distance (Horn B., 1981). The light beam has a constant azimuth and an elevation angle for the entire area. The azimuth is the direction of the sun. An attempt was made with different settings to find the right parameters for the structures of interest. The advantage of hillshading is its simple, intuitive usage and fast calculation. Small elevations can be visualized by decreasing the angle of incidence and letting the light shine from an increasingly oblique angle. A disadvantage is the one-sided lighting, which makes some elevations unrecognisable since the cast shadows may occlude structures. When the azimuth is set in a way that the simulated sun rays are parallel to structures, then the structures are not recognisable. Several results with different azimuths were generated and attempts were made to combine several levels so that one-sided light exposure is not a problem.

### Sky View Factor

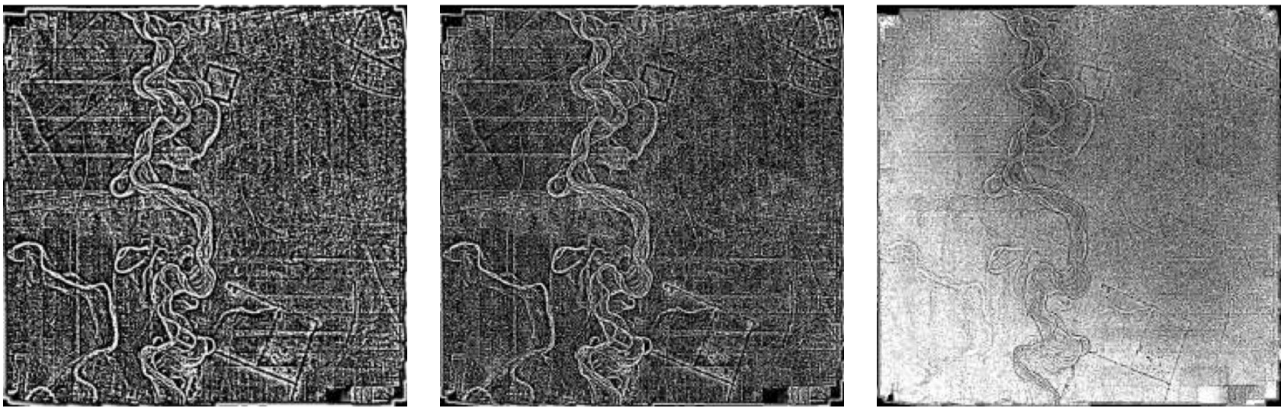
An alternative to the hillshading method is the concept of the sky view factor (SFV). Like hillshading an imaginary light source is used. An imaginary light source illuminates the relief from a hemisphere, which is centred at the point being illuminated (Zaksek, Oštir, and Kokalj, 2011). The computation of SVF is influenced by the search radius. The larger the search radius, the more generalised the result. A small search radius can be used to visualise and classify local morphological forms. For example, a 10 km search radius can be used in meteorological studies, while a 10 m search radius is suitable for archaeological features. Local flat terrain, ridges and earthworks which receive more illumination are highlighted and appear white, while depressions are represented by dark pixels because they receive less illumination. Different radius sizes were tested. Larger sizes required a significantly longer calculation time. Better results were achieved by using a smaller radius, since archaeological structures are not very big. Comparing hillshading and SVF, SVF produces better results on complex shapes (see Fig. 4). The output is clear and easily recognisable.

### Topographic Openness

Topographic openness is similar to SVF, the only difference being that an entire sphere is considered. When using topographic openness, the first deliberation is to choose between positive or negative openness. Positive openness is specified for convex shapes and negative openness is used for concave shapes. Since the sky view approach is similar to topographic openness, the same factors have to be considered. The radius determines how much information is considered from the environment.

### Trend Removal

Most of the time, the archaeological features are smaller in dimension than the dimension on the landscape forms on which they lie (Opitz, 2013). One procedure that separates small local features from large landscape features is the trend removal method. The information from rough landscape structures can be saved in a smoothed DEM.



*a* *b* *c*

*Fig. 5. Trend removal is a way to focus on structures of a specific size. The smoothing filter effects and controls how much of the landscape information is ignored. The bigger the size of smoothing, the smaller structures are visible. Different sizes were tested a)5; b)9; c)17. (© DAI/Huy Do Duc)*

This information can be subtracted from the original DEM, leaving only the local characteristics. The more the image gets smoothed, the more information will be subtracted from the original height of landscapes. If the smoothing is weak, the differences are minor. Various smoothing filters were tested on the smoothed DEM (see Fig. 5). Smoothing with the box filter can be calculated quickly. But the disadvantage is that the filter offers no distinction between homogeneous surfaces and edges. The Gaussian filter can distinguish between steep and slightly rising or falling changes. The level of smoothing is defined by the kernel size of the filter, where a smaller kernel exposes smaller features. The precise kernel size should reflect the size of the small-scale landforms. The method works best on terrain with gradual slopes, where it can produce artefacts where the relief is changing rapidly. Some tests show that trend removal works better for landscapes with a slight slope.

Certainly, more visualisation methods of digital elevation models exists. Nevertheless, it is necessary to know how different visualisation techniques work and how to use them to best advantage according to the data, general morphology of the terrain, and the scale and preservation of features in question. When a certain technique is chosen for detection or interpretation of features, it is particularly important to know what the different settings do and how to manipulate them. Because the techniques show various features in different ways, emphasising edges, circular or linear forms, a combination of methods is recommended.

## Image Processing

Different surface forms can occur: flat surfaces, summits, sinks, mountain ranges, valleys, rises, concave or convex shapes. Each visualisation method reacts differently to the respective forms. Looking closer at the unprocessed DEMs, different structures are already visible. With the combination of visualisation methods and image processing structures, building remains, and interesting patterns should be found. It is important to know what these structures look like and how significant they are, to distinguish them from the remaining landscape features. The structures vary in shape and complexity, so it was difficult to filter out certain features. Image preprocessing steps like edge detection, morphological operations or histogram stretching are required to display features more clearly.

### Morphological Operations

Morphological operations or filters were originally developed for binary images in order to either connect, strengthen, thin out or separate geometric structures (Kaur and Garg, 2011). An alternative usage for the morphological filters is to remove noise. There are two types of morphological operations: erosion and dilation. By combining these two morphological operations structures can be opened or closed, meaning that they are merged or separated, depending on their shape and proximity (see Fig. 6).

*Fig. 6. Combining the Canny edge detection and morphological operations is a good way to analyse specific areas. The first row of images shows different thresholds of the canny algorithm. The second and third rows present the usage of dilation and erosion. Through the combination of dilation and erosion it is possible to close or open structures, especially useful for noisy data. (© DAI/Huy Do Duc)*

### Image Segmentation

When segmenting, the goal is to separate contiguous areas from the rest of the image. There are methods that are based on pixels, regions or edges. Adjusting and testing different edge filters were necessary to make hidden structures more visible. In this work, the key focus was on edge detection. The limits of classic edge filters had been reached. The Canny algorithm (Canny, 1986) provides clear edge images when the threshold values are selected correctly. Nevertheless, the Canny edge filter is only able to detect local differences. Certain thresholds can work for only one image, but they have to be adjusted for another image. Further context information is not considered. Deep learning could solve this problem. The holistically edge detector (HED) produces satisfying results for different kinds of images (Xie and Tu, 2015). It was tested how to see HED reacts to aerial photos and digital elevation models. The Canny edge detector provides a lot of edges, but too many lines lead to unclear interpretation (see Fig. 7). Many of the small, disruptive edges could be removed with morphological operations. Nevertheless, the results show that it still needs the help of a human to adjust the appropriate parameters to recognise certain structures.

## Module DeepStructure in ArchaeoAnalytics

A tool named DeepStructure was developed and integrated in ArchaeoAnalytics to help users find interesting areas in large data sets quicker and make them more visible. A pipeline was created that combines the strengths of visualisation techniques and image processing. The automation of individual phases simplifies the work and enables a faster processing of data. Generating a map from point clouds takes several steps. Some of these steps were automatized. Scripts were written for the interpolation of point clouds and georeferencing a batch of images. Visualizations such as hillshading, sky view factor, trend removal and topographic openness can now be performed on several data in one step.

## Preliminary Results and Outlook

An attempt was made to improve existing visualizations and to create meaningful images that preserve the positive properties of individual technologies. The combination of several technologies makes it possible to see different topographical features in one image. Nevertheless, there is a risk of wrong use. Important landscape features might be missed or even removed. It is therefore of great importance that the information about the raw data, scan density, methods of generating the DEMs and the visualization methods used are well documented. Thus, the assessment of artefacts can be performed better later.

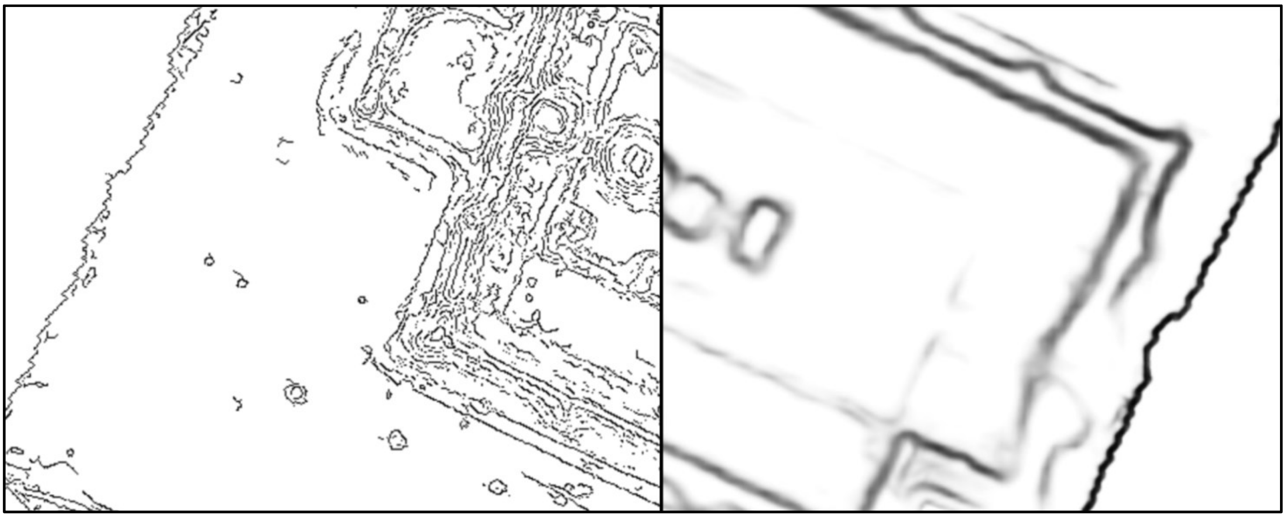


*Fig. 7. Comparing the canny and the holistically edge detection the results are quite distinguish. The canny algorithm shows a lot of small lines. HED produces fewer structures which are thicker. From distance the results of HED are clearer but on the other hand small features get lost. (© DAI/Huy Do Duc)*

While the methods explained above all have their strengths and weaknesses, a first assessment of simple hillshade visualisations already proved the high potential of the collected data. The digital elevation models (DEM) derived from the UAV imagery by the webservice DroneDeploy allow even faintest remains of human settlement activities such as eroded walls, platforms, ditches and fields, to be distinguished. However, the DEMs also have some quality-issues. There are a lot of artefacts visible on the DEMs, which sometimes make interpretation difficult. Experimental tests with other Structure-From-Motion algorithms will show if better results are possible with the data gathered in the field. This would improve the basis for the application of the visualization and image processing methods detailed above.

Although data processing and analysis is still in progress as the team experiments with different methods, a first glance on the results shall be given here. The most important achievement of the data collection campaign in Mongolia 2018 was that a complete high-resolution DEM of the ancient site of Qara Balğasun was accomplished. A schematic drawing of the structures visible in the DEM shows interesting patterns. The remains of the city sprawl over 44 km². It had the shape of a crescent with its convex side facing to the west and its flat side facing east. The so-called temple and palace complex or "imperial city" is situated at the centre of the straight eastern border (Termed "HB 2" in Fig. 8). This is a genuinely nomadic layout of a city, resembling a royal encampment. This is an interesting contribution to the discussion on urbanity in a nomadic context (Franken et. al., 2020). These first results demonstrate the capabilities of UAV-based mapping also for large sites and even on the landscape scale. In future projects the team aims to further develop the methodology and to extend the surveyed area to approach a more holistic view of settlement and land use at the urban sites of the Orkhon Valley.

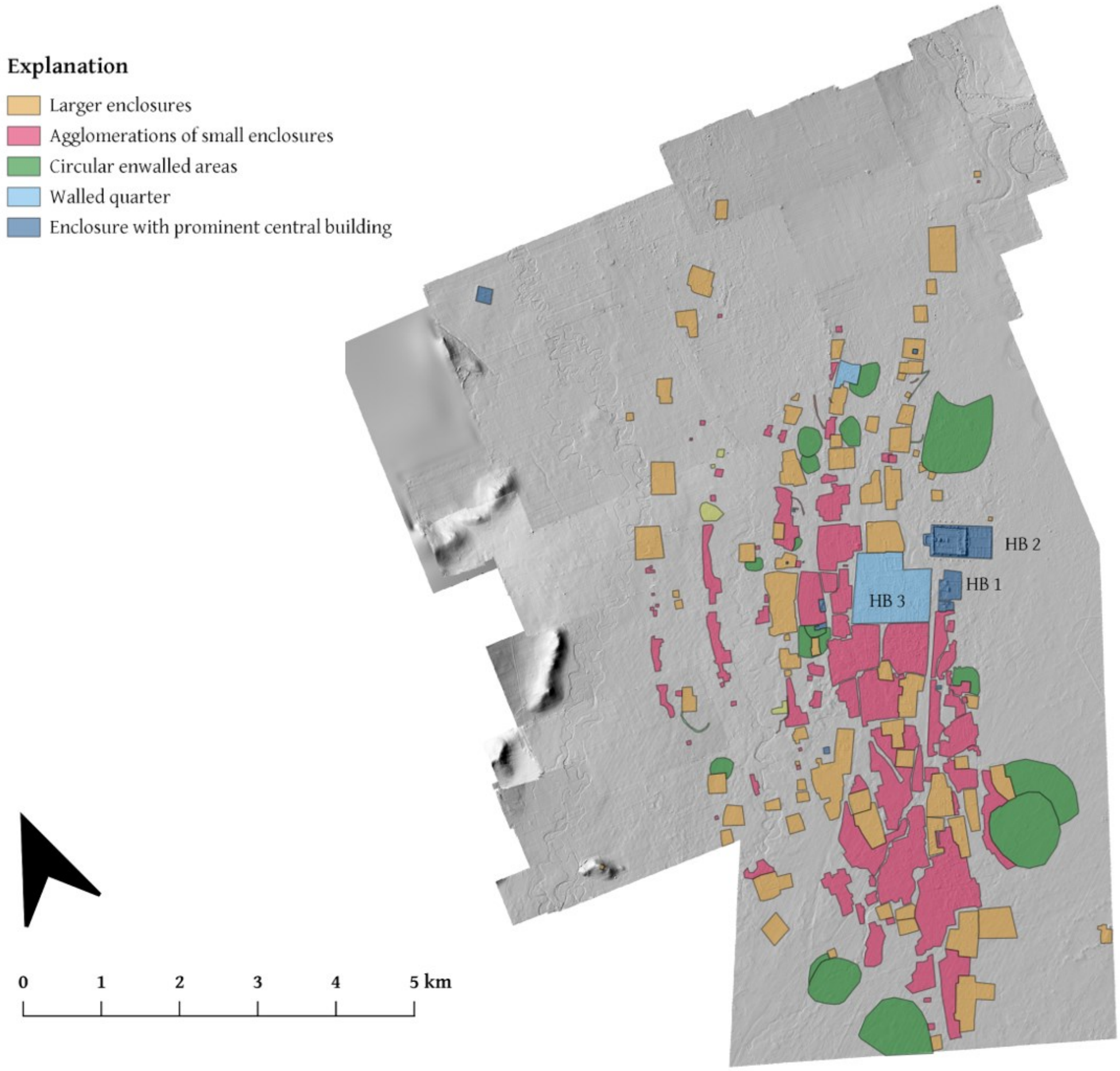



*Fig. 8. Schematic rendering of the remains of Qara Balğasun. The temple and palace complex is marked as "HB 2". (© DAI)*

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# Image based Aerial 3D Documentation of Inaccessible Archaeological Sites using UAS

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**Abstract:** The following paper refers to the Large-Scale Documentation of Cultural Heritage in extreme regional and environmental conditions, with the use of Unmanned Aerial Systems (UAS). Three large scale survey sites in Greece are presented, all located in Southern Greece at the Peloponnese region. Case studies are: The Old Philosopher's Monastery, the Penteskoufi Fortress, and the Acrocorinth Castle. The paper focuses on the encountering difficulties on site, the methodology and techniques used for surveying, the workflow followed during documentation and the deliverables of each study.For each case study, detailed documentation of the difficulties faced on site due to inaccessibility takes place. The most common problems for the working team where: extremely bad or quickly changing weather conditions, dense vegetation that covered the surveying sites, frequent rock falling, lack of power charging spots near the site and the inability of transporting heavy equipment. Additionally, the combination of methods applied to overcome every challenge is elaborately presented. The sites were surveyed with the use of Unmanned Aerial Systems supported with high accuracy geodetic equipment. Stereoscopic Photography took place not only in vertical and horizontal position, but in diagonal also, in order to capture detailed aspect and all the ground folds. Finally, using 3D Photogrammetry, billion numbered Point Clouds, Digital Surface Models (DSM), Digital Elevation Models (DEM), 2D Cad Blueprint visualizations and Orthophotomosaics were generated.

***Keywords:*** *photogrammetry—aerial—inaccessible—documentation—large scale—castle—3D*

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## Old Philosopher's Monastery

### Precise Documentation & Survey in Inaccessible & beyond line-of-sight UAV flights

The Old "Philosopher's" Monastery is located in the gorge of the Lousios River, south of Dimitsana in the Peloponnese region. The impressive steep gorge extends for more than 15 km and forms an important National Park. The founding of the monastery and the first construction phase dates back to the second half of the 10th century A.C. It is built in a natural cavity of a vertical rock, with a total length of 300 m. The complex has a minimum width of 50 cm and a maximum of 6 m. The smallest preserved height of the Monastery's walls is 3 m while the maximum is 10 m high. A one-kilometer narrow path through the gorge is the only way to access the monastery. The issues to be resolved for the 3D documentation of the monastic complex were:

1. Dense vegetation inside the gorge (tall and thick trees) and the lack of satellite connection prevented the lift-off, of a UAV from a spot close to the monastery. At that time, no vision system stabilizers were commercially available for heavy lift UAVs.
2. Extremely dangerous frequent rock falling, necessitated choosing the fastest possible documentation method. Therefore, a 3D Terrestrial LiDAR Scanner was used in the interior.

The dilapidated condition of the monument, in conjunction with the rockfall and the difficulty of access, required a detailed documentation in the shortest possible time, including both the monastery and the surrounding environment of the natural rock. In the interior of the Monastery natural & artificial GCPs (ground control points) were installed and measured by geodetics, to support the Laser Scanning.[1]

The exterior of the monument was decided to be documented with the use of a UAS and photogrammetry method.[2] The monument had eventually been approached from the opposite side of the gorge, although an automated UAV flight was very difficult due to lack of satellites. Due to the peculiarity of the terrain, there was a limited angle for satellite signal and no mobile phone signal. Beyond Visual Line of Sight (BVLOS) UAV skills, alongside with the aid of sporadic and low accuracy GPS tracking of a handheld GPS unit, were used to overcome the above issues. Many probationary flights took place, in order to define the exact distance and height that the UAV had to fly for best photography results. Four routes at different heights were finally used, delivering more than 14,000 close face shots, of both the monastery exterior walls and the rock formations beneath and above the complex.[3]

The field survey took place from 10 to 17 of April 2014 and a two-month period was required for the processing of the data and the elaboration of the Restoration study. The photogrammetric processing of the photos taken in combination with the 37 terrestrial laser scans delivered:

- Billion numbered Point Clouds,
- Digital Surface Models (DSM),
- Digital Elevation Models (DEM),
- Orthophotomosaics of the facade with a 3 mm pixel size & 5 mm accuracy and
- 2D Cad Blueprint visualizations, both of the Monastery and the rock above.

The geotechnical study for the stabilization of the falling rocks, was significantly aided by the previous derivatives. The 3D created rock model determined the way of transporting building materials for the restoration of the monument. A revealed cavity near the top of the gorge allowed to a special crane move downwards all the materials needed for the restoration.

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[1] Terrestrial Laser Scanners used for the survey of the inside: Leica C10 & Leica MS50. Total Station used for the geodetics : Leica MS50.

[2] The used UAS/UAV was a custom made octocopter assembleded & set up by IMANTOSIS.It was set for BVLOS action, with lifting capability of 25Kg in order to resist the gusty winds, equipped with a 5D gimbal & a DSLR camera.

[3] DSLR camera used: Nikon D800 36Mp Full Frame / Lens : Nikon AF-S Micro Nikkor 60 mm.

*Fig. 1. Orthophotomosaic / Facade of Old Philosopher's Monastery (© IMANTOSIS [2014]). Details of original Orthophotomosaic: accuracy 1cm / pixel size 3 mm / more than 300 physical targets all measured by robotic total station & 3D Scanner. Processed & Produced in Agisoft Photoscan Software.*

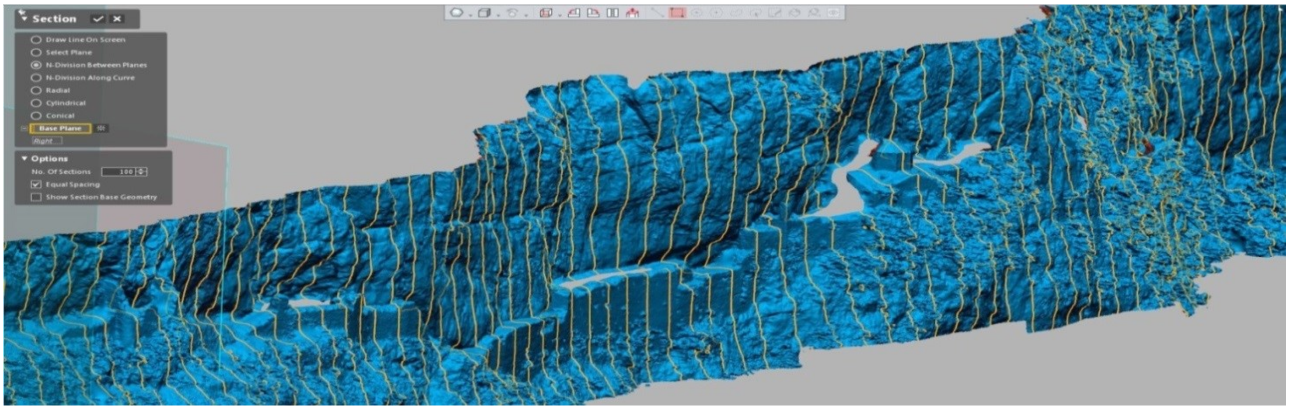


*Fig. 2. Digital Surface Model (DSM) & Computer Aided Tomography Scan (CT scan). Facade of Old Philosopher's Monastery & natural rock. Processed & Produced in Agisoft Photoscan Software. Post processed in 3DS Geomagic Studio Design Software (© IMANTOSIS [2014]).*

## Penteskoufi Fortress

### Precise Documentation & Aerial Survey against adverse weather

The "Penteskoufi Fortress" project, encompasses all the methodology deployed on workflow during documentation of inaccessible Archaeological sites. The Fortress is located on one of the two unique elevations of the generally flat landscape near Ancient Corinth, at a height of 500 m above sea level. With 600 $m^2$ surrounding area and 100 m of the snakelike fortress wall and a rectangular tower, it stands on the peak of a fortified rugged rock, enclosing an area of 8,000 $m^2$. An one-hour hike in a medium difficulty terrain is needed to reach the Fortress. The survey expedition had to face the following challenges:

1. The gusty winds demanded the use of a UAS capable of lifting heavy loads and operating in difficult conditions of extreme wind resistance and light rain.
2. The dense low vegetation on the fortress hid 80 % of both the monument and its significant elements. A complete clean-up was decided to unveil the fortresses' details. However, due to the rapid regrowth of the vegetation, detailed and precise documentation had to take place rapidly, regardless of weather conditions.
3. The use of 3D Terrestrial Laser Scanner was excluded due to the distance from the provincial road, the hike needed to approach the monument and the inability of transporting heavy equipment. In addition, no suitable area existed for setting up such equipment.

4. Traditional time-consuming measurements supported by geodetics, could not fulfill the requirements of capturing all the details.

The potential loss of details or larger elements of the fortress due to collapse, required detailed three-dimensional representation of the entire monument. The field survey and the processing of the data took place in March 2013. The Survey included the fortresses' surrounding natural area, in order to collect all the necessary scientific evidence that would allow restoration and a reconstruction study to take place in case of a complete loss. An octocopter Unmanned Aerial System was deployed, with a 25 kg lifting capability to withstand the usual 7 Beaufort gusty winds. Automated flights aided by a ground station, performed to acquire 5,000 full frame shots.[4] In order to secure accuracy, the position of the fortress in the Greek Geodetic Reference System, 27 GCPs were measured by a ground GPS/GNSS.[5] Scale accuracy of the digital photogrammetric derivatives was assured by the installation of 300 artificial CPs.[6] For the geometry enhancement of the Digital Surface Model, physical CPs were matched at the office's Photogrammetric Station. Billion numbered Point Clouds, Digital Surface Models (DSM), Digital Elevation Models (DEM) and Orthophotomosaics of the facades with a 3 mm pixel size & 5 mm accuracy were generated.[7] Especially for the snakelike geometry of the walls, the photogrammetric Station had to be fused with algorithms capable of creating an isometric unfolded view of the facades.[8] The 3D rock and fortress model determined areas with a high risk of collapse and others in urgent need of salvage downs.

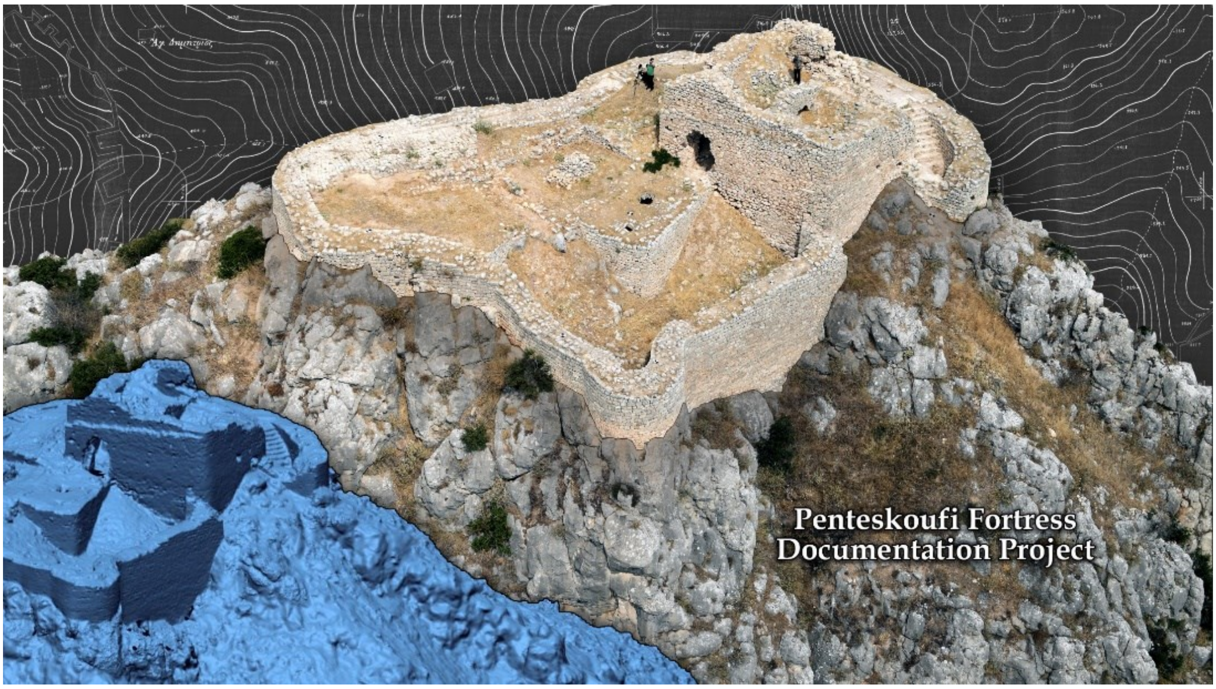


*Fig. 3. Aerial View & Digital Surface Model (DSM) / Penteskoufi Fortress (© IMANTOSIS [2013]).*

[4] The used UAS/UAV was a custom made octocopter assembleded & set up by IMANTOSIS.It was set for High Wind resistance action, with lifting capability of 25Kg, equipped with a 5D gimbal & a DSLR camera . DSLR camera used: Nikon D800 36Mp Full Frame / Lens Nikon AF-S Nikkor 50 mm.

[5] GPS / GNSS used : Leica Viva GS08plus Receiver.

[6] Total Station used for the geodetics : Leica MS50.

[7] Proccessing Photogrammetry Station : Agisoft Photoscan / Post proccessing : CapturingReality.

[8] Unfolded photomosaic parts produced in Lupos3D. Color refinements were performed in Adobe Photoshop CS6.

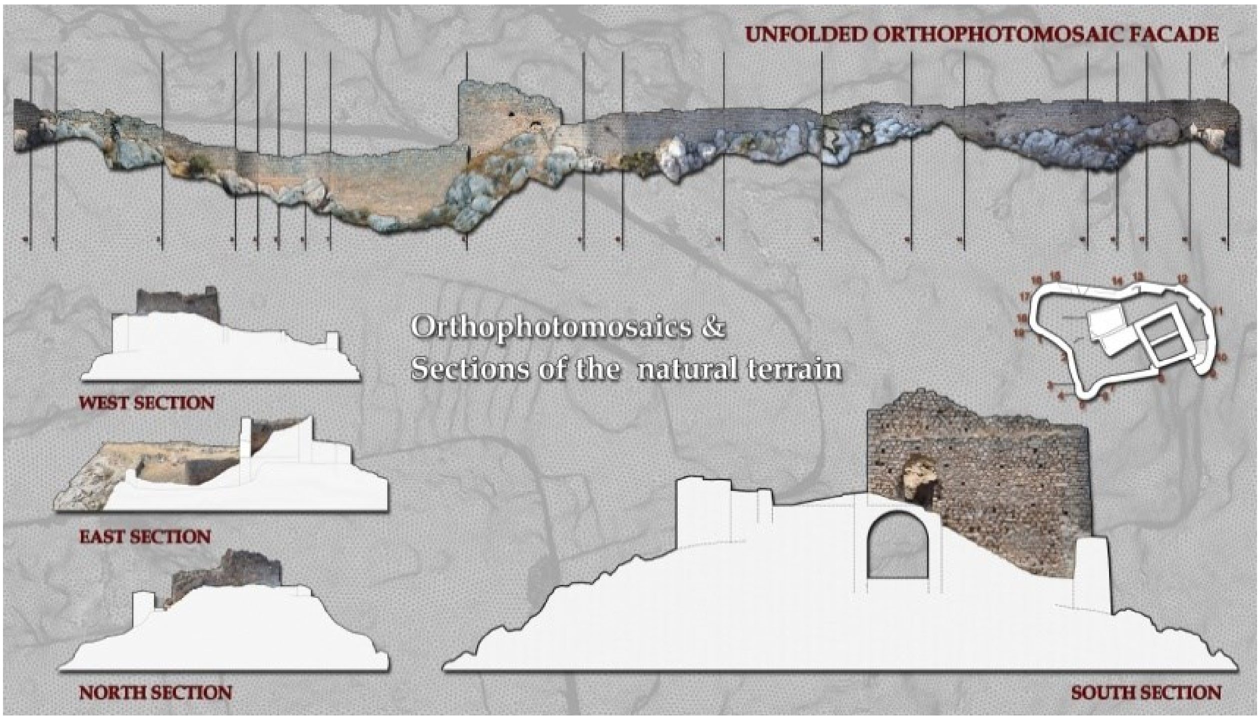


*Fig. 4. Orthophotomosaics & natural terrain sections of the Penteskoufi Fortress. Unfold produced in Lupos3D. Color refinement in Adobe Photoshop CS6 (© IMANTOSIS [2013])*

## Acrocorinthos Castle

### Large Scale Precise Documentation

The steep rock of the Acrocorinth rises to the south west of the ancient Corinth. It is dominated by the fortress, also called the Acrocorinth. It was the fortified citadel of ancient and medieval Corinth and the most important fortification in the area, from Antiquity till the Greek War of Independence (1821 A.C.). It lays 600 m high above sea level and its walls run for almost 5.5 km encircling an approximate area of 300,000 $m^2$.

Three fortification zones lead to the interior of the Castle. Inside the Castle, Remains of various periods such as Mycenean megalithic fortifications, ancient sanctuaries, early Christian vasilicas, Byzantine cisterns, a Frankish tower, a Venetian church, mosques, settlements, and fountains, reveal the significance of the Settlement. Materials in second use, often make it difficult for experts to date and distinguish historical and construction phases.

The field survey took place between September 2013 and April 2014. A six-month period was required for the processing of the data and the production of final derivatives. The team had to deal with common type of problems but on an enhanced scale. UAS large scale documentation involves the use of GIS background. Most of the U.A. Systems use as default, the Google Earth platform as a visual interpretation, to plan the flight missions. In a region with no obstacles, it might be of no concern. On the contrary, where intense terrain is to be documented, involving steep rocks and gorges, mission setup requires high navigation accuracy, aided by precise geographic coordinates. Precision is crucial, to prevent crashing on physical elements, leading to a complete loss of the expensive Aerial equipment and the collected Data. In the Acrocorinthos project, the Google Map location error was more than 30 m horizontally and 5 m vertically, making flights risky.

In order to overcome the risk of damaging the UAV, mission plans were set at gradually inclining levels following the steep and raged anaglyph, keeping photography distance constant by the use of specified Geographical Coordinates. Lack of previous existing documentation surveys to organize the operations in advance led to new ground measuring GPS/GNSS data, that were inserted directly to the UAS algorithm.[9] Stereoscopic Photography took place not only in a vertical and horizontal position but also in diagonal, in order to capture detailed aspect and all the ground folds.

The sheer rock elevation necessitated splitting the Survey into subsections. Moreover, the area covered by the UAV on a single flight was also depending on the prevailing weather conditions. As long strong winds were raising, flight time decreased dramatically due to battery consumption, because of the effort necessary to overcome the wind's resistance.[10] A misplaced and inaccurate flight could lead to increased field-work time, with financial & time derailment consequences. Planned missions that were not performed, after all, led to the loss of all the installed GCPs, which had to be reestablished the day after, as the quality of the measurement was not guaranteed. Targets could have been moved or deformed by weather conditions animals or curious visitors.

Taking all the above into consideration and having the intention of a 3D high accurate photogrammetric documentation, the missions of the UAV were set “traverse” like, trying to achieve a closed-loop survey after the 5.5 km campaign. In addition, one of the major problems faced, was the seasonal changing, as the field operation took more than eight months. For a non-fully automated alignment on a Photogrammetric WorkStation, it is obligatory not only to use artificial control points but also plenty of natural ones. Otherwise, Photogrammetric Station's algorithm may not achieve to detect & solve the geometries & levels. That's due to Photogrammetric Station's weakness to pinpoint the same optical elements on pixels, which change color due to the vegetation, rock movement, subsidence and other – as the seasons pass.

More than 250 aerial missions took place, with more than 170,000 36Mp-high-resolution photos collected data. Fed in a render farm, the photogrammetric station produced a Trillion numbered Dense Point Cloud of 3 mm point spacing. The Point Cloud Accuracy was fused by the dense network of installed ground control points (GCPs) that was acquired by a total station and georeferenced by GPS/GNSS. Some areas were surveyed more than once during the excavations, in order to record all the historical phases. Digital Surface Models (DSM), Digital Elevation Models (DEM) and rendered models were delivered for presentations of the castle.

[9] GPS / GNSS used : Leica Viva GS08plus Receiver / Total Station used for the geodetics : Leica TS06.

[10] The used UAS/UAV was a custom made octocopter assembleded & set up by IMANTOSIS. It was set for High Wind resistance action, with lifting capability of 25Kg, equipped with a 5D gimbal & a DSLR camera. DSLR camera used: Nikon D800 36Mp Full Frame / Lens Nikon AF-S Nikkor 50 mm.

*Fig. 5. Aerial Photos & signalization of the main Walls of Acrocorinthos Castle (© IMANTOSIS [2014]).*

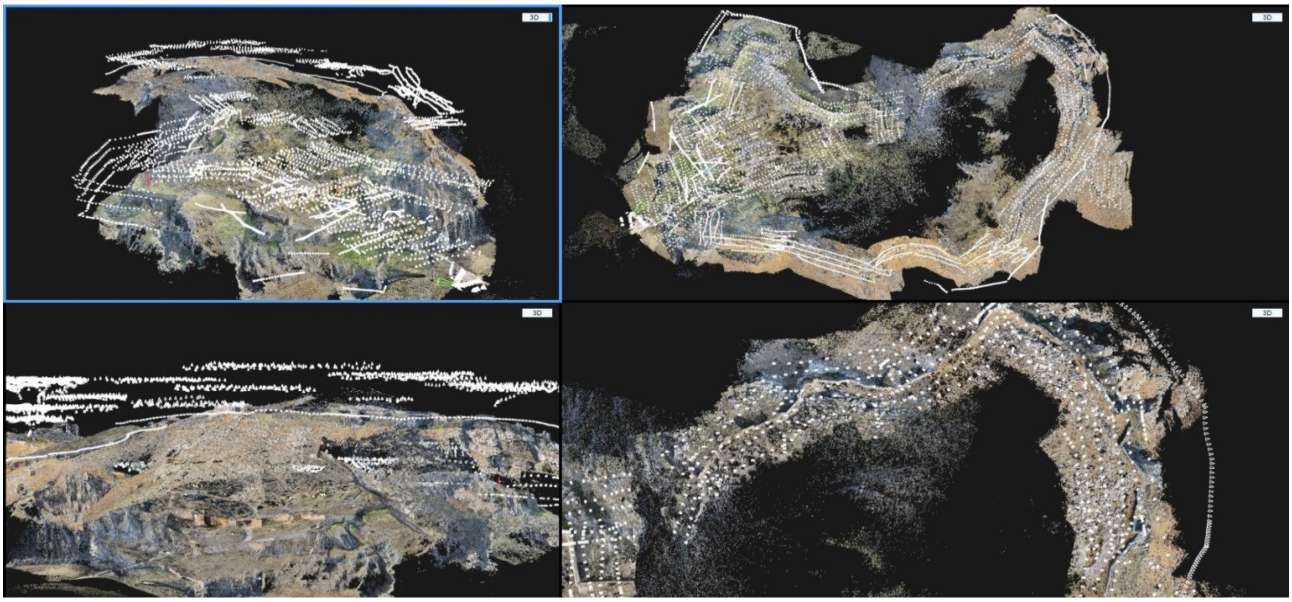

*Fig. 6. Snapshots inside the Photogrammetric Station / Photography alignment process. Processed & Produced in Agisoft Photoscan Software. Post processing in CapturingReality Software (© IMANTOSIS [2016]).*

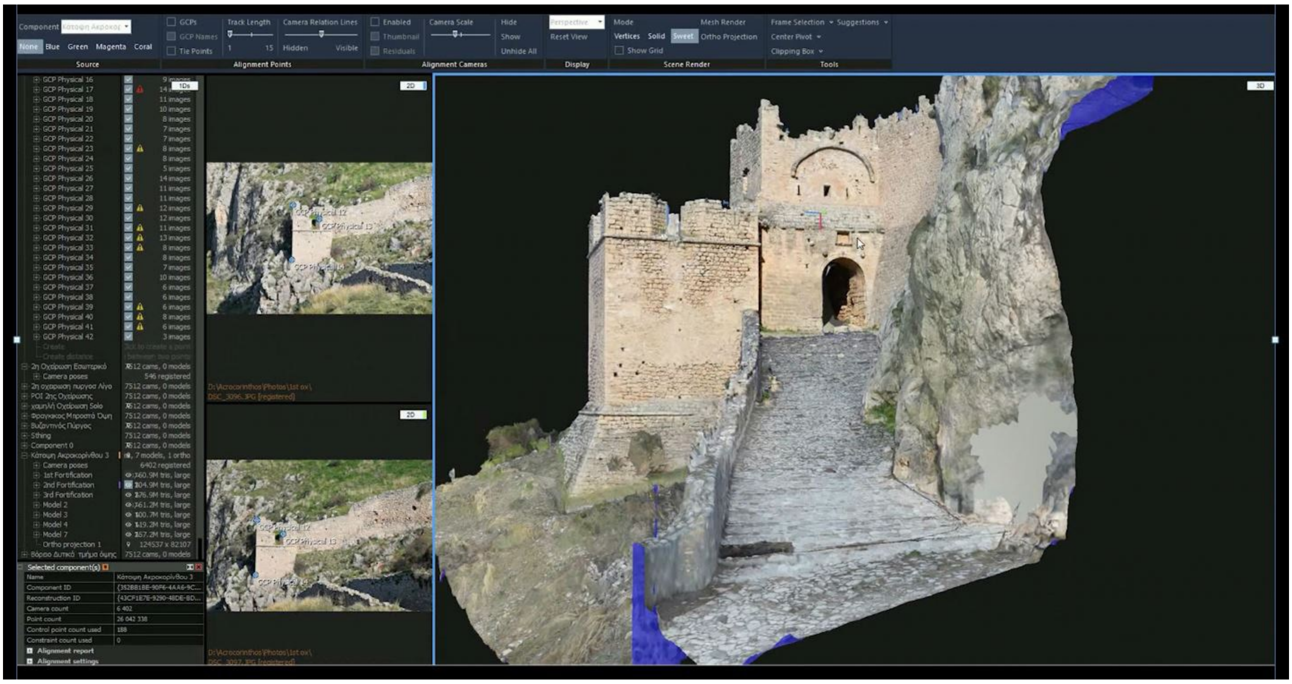

*Fig. 7. Snapshots inside the Photogrammetric Station / Virtual Reality (VR) Visualization. Post processed in CapturingReality Software. (© IMANTOSIS [2016]).*

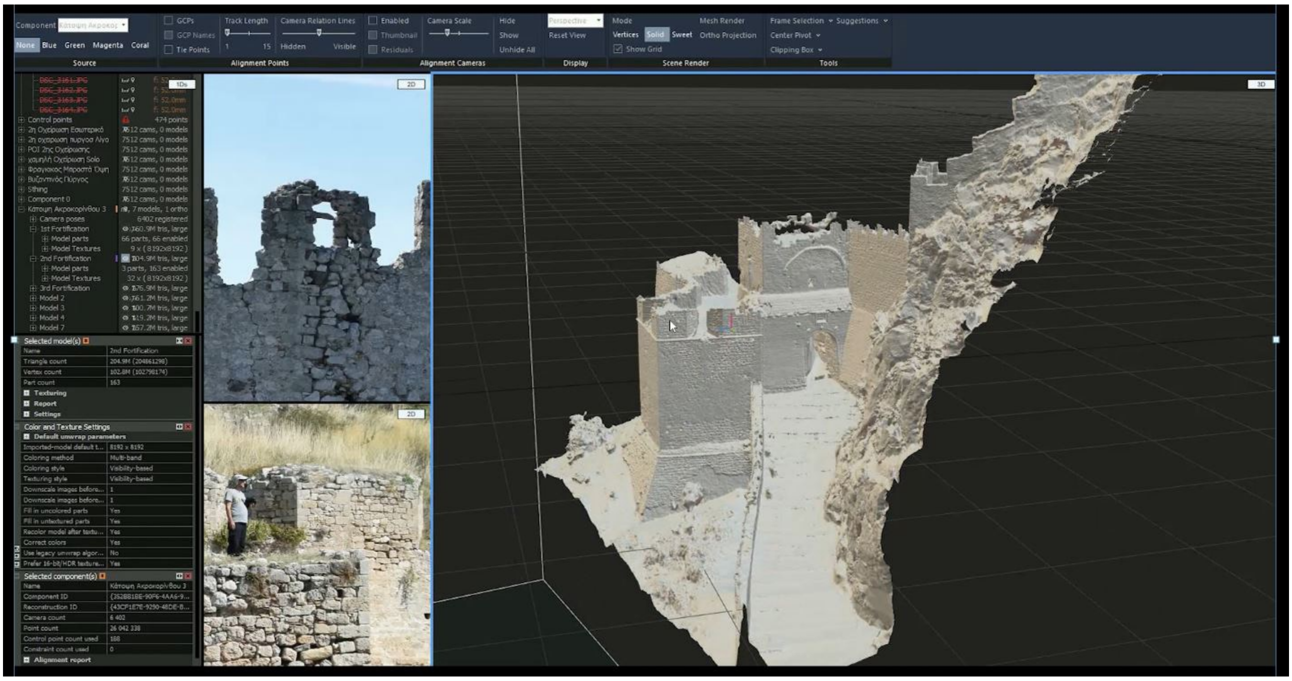

*Fig. 8. Snapshots inside the Photogrammetric Station / Mesh Topology Generation & Process. Post processed in CapturingReality Software. (© IMANTOSIS [2016]).*

*Fig. 9. Orthophotomosaic / Part of West Fortification of Acrocorinthos Castle (© IMANTOSIS [2014]). Details of original Orthophotomosaic: accuracy 1cm / pixel size 3 mm / 50 artificial ground targets (GCPs) & more than 400 physical targets all measured by total station. Processed & Produced in Agisoft Photoscan Software.*

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# Documenting and visualizing deterioration of monuments on a 3D environment

## Projection of 2D documentation drawings on a 3D SfM model

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**Abstract:** The purpose of this study is to display a building's structural condition, through the use of multiple layers, inside a 3D digital environment. The creation of interactive 3D models, that incorporate vector and raster documentation, for non-pervasive studies of historical monuments in Cultural Heritage, could in many ways facilitate a study by offering a mix of advantages. The object of study is a small Ottoman hammam, a listed monument, which is located in the village of Mournies, Chania, in Crete. It is a building of great historical and architectural interest which has an impressive amount of rare, decorative and morphological elements. Several deteriorations are located, that vary depending on where they are and require immediate restoration. This paper presents the process of creating a 3D documentation model that could be considered as a multiple-use documentation tool. The main stages of this process are Work on site, Creation of Virtual Replica, Creation of 2D documentation drawings and Creation of 3D documentation. Although the quality and timing of the outcome depend on some technical features, the 3D documentation model can be created using common software and hardware. It is a fast, low cost and flexible technique for documenting and visualizing deterioration of monuments in a 3D environment and offers the potential for future work.

***Keywords:*** *3D documentation—virtual archaeology—structure from motion—cultural heritage—deterioration*

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doi: 10.11588/propylaeum.747.

## Introduction

### Team, vision and objective of research

The following research was realised under the Postgraduate Programme "Space, Design and Built Environment", in the School of Architecture at the Technical University of Crete, for the 3D visualization of structural damages and deteriorations of an ottoman hammam using common software and hardware.

The vision is the existence of a tool helping in overall perception, by non-pervasive studies, of a monument's condition. This tool could support the decision making process at any stage, from first contact and sketches till detailed specialised documentations. To be enhanced this tool should be a bridge of communication between the professionals involved in the monument study as well as for anyone else interested from any distance (in cases where the monument is not safe to visit).

The goal is to create an interactive multi-layer 3D model that could incorporate vector based and raster-based documentation.

The ability to create a three-dimensional replica of a monument could in many ways facilitate a study by offering a mix of advantages (Table 1). The researcher could make observations about the actual scale and condition of the monument, in almost the same quality and detail as in situ, while retaining the advantages, the flexibility and the security of his office.

| Characteristics | In situ | 2d environment | 3d environment |
|---|---|---|---|
| Safety – Comfort | | ● | ● |
| In detail observation | ● | | ● |
| Move freely | | | ● |
| Zoom in – Zoom out | | ● | ● |
| Multi-layering Observation | | ● | ● |
| Hardware independence | | ● | |

*Table 1. Comparing Observation Methods' Benefits.*

The typical procedure for studying a historical monument requires multiple visits to the monument to repeat the observation. Photographic recording can only be used as documentation. The proposed procedure (Fig. 1a) replaces a significant proportion of these visits with digital replica's visits. This enables a faster, equally qualitative, safer, and more economical examination of the monument.

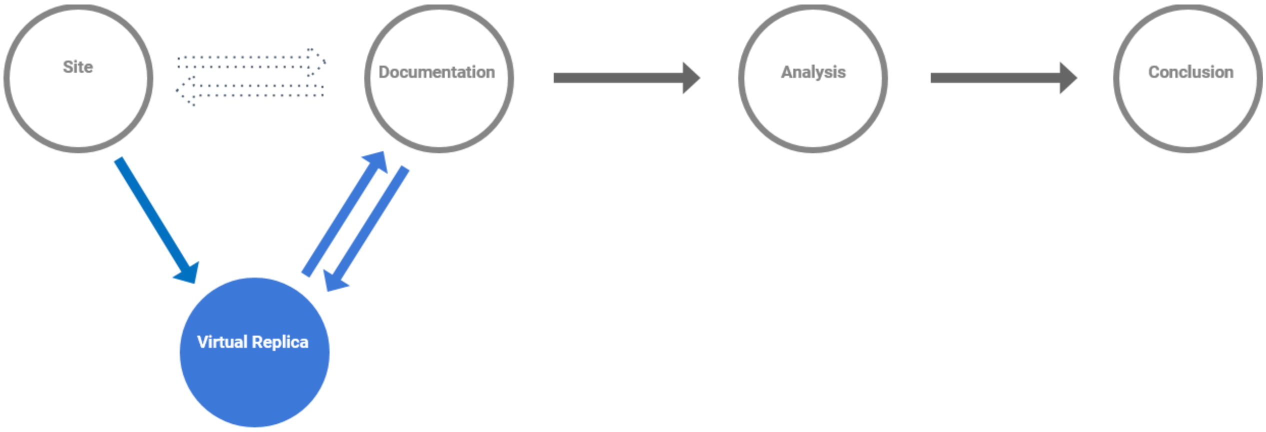



*Fig. 1a. Suggested Workflow – Partly replacement of site by a Virtual Replica improving visitability and quality of observations.*

In this paper, the above workflow it is implemented (Fig. 1b) using:

1. Structure for Motion (SfM) method and Agisoft Photoscan software for the creation of Virtual Replica
2. Autodesk Autocad for vector documentation
3. Adobe Photoshop and Photoshop 3D for raster documentation
4. Adobe Photoshop 3D for incorporation of raster and vector documentation
5. Sketchfab as online viewer

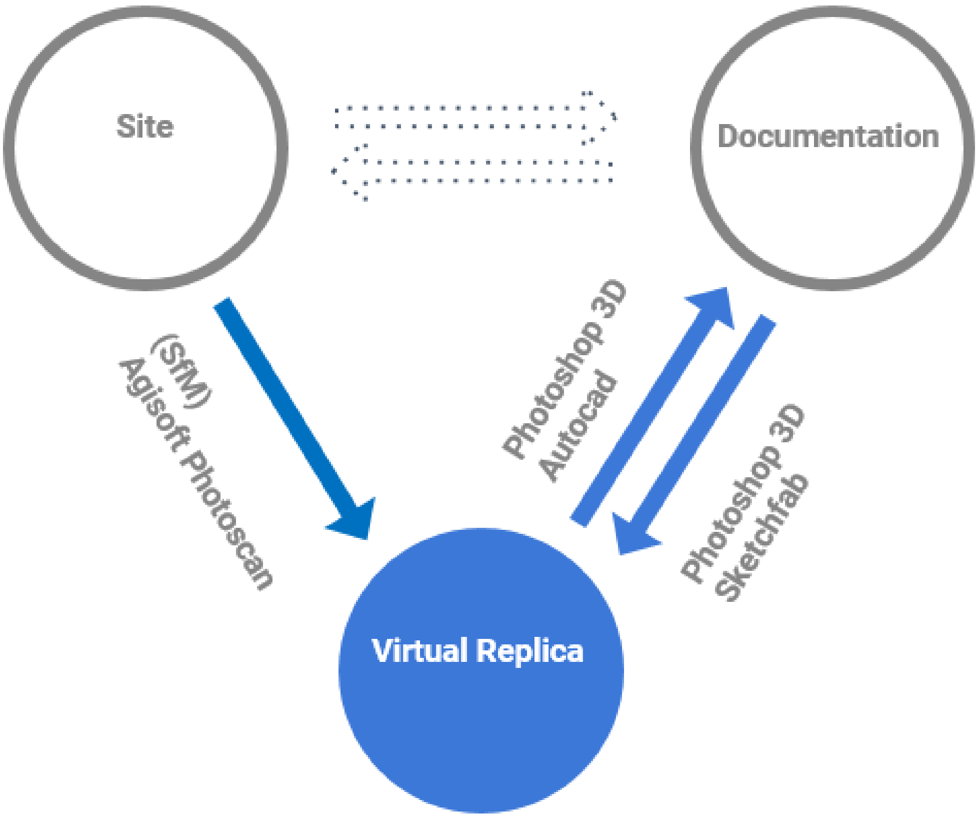



*Fig. 1b. Case Study Workflow.*

## Case Study

### Historical information

The listed monument is located 4 km south of the city of Chania, Crete, in the settlement of Mournies (35°28'56.6"N 24°00'39.5"E), in an old privately owned area. The building hosted a Turkish hammam and has a great historical and architectural interest, as well as an impressive amount of decorative and morphological elements (Fig. 2, Fig. 3). Hammams were typical buildings of the Islamic world. The spaces were designed according to operational criteria and the basic layout was similar in all buildings.

*Fig. 2., Fig. 3. Decorative and Morphological Elements.*

### Condition – Deteriorations

Constructively, the particular hammam is made of a semi-carved stone masonry, it has a number of damages and deteriorations, and needs immediate restoration. Its construction was quite complex due to the configuration and maintenance of the optimum indoor temperature and humidity conditions for the operation of the hammam. The different mortars and coatings used per room relative to the operation of each space have brought different types of deterioration.

The building due to long-term abandonment presents considerable damage, with a significant crack in the intermediate semicircular dome. At the same time, rising moisture and covering much of its outer envelope with vegetation and soil are constant aggravating factors (Fig. 4).

| DETERIORATION | MAIN FACTOR |
|---|---|
| Material loss | rising humidity |
| Mortar loss | rising humidity |
| Plaster loss | rising humidity |
| Mould | moisture retention on the roof exterior |
| Cracks | static and dynamic loads |

*Fig. 4. Section -Main Deteriorations.*

## Process, tools and methodology

### Work on site

Two visits took place on site. On the first visit, the monument was identified and the lack of adequate natural indoor lighting for the subsequent photography was recorded. On the second visit, photogrammetric capture took place, taking 195 overlapping photographs (Table 2) that were used in the next stage. The photo shooting took place only inside the hammam, as it was impossible on the outside due to lack of accessibility. A Canon EOS 450D camera and a LED strip of about 3 m, 6400 K, 10.8 w / m, 1000 lumens / m for interior lighting, were used. The largest area illuminated with the above equipment had dimensions of 3 m×3 m and an average height of 4.5 m.

| Camera Details | |
|---|---|
| Company | Canon |
| Model | EOS 450D |
| ISO | 400–800 |
| Focal Length (mm) | 18 |
| Aperture | F/3.5 –F/6.3 |
| Exposure Time | 1/13–1/100 |
| Tripod | No |

*Table 2. Camera Details.*

### Virtual Replica

The next stage of the process was the virtual 3D reconstruction using a common desktop PC (Table 3), using SfM in Agisoft Photoscan software (Table 4), where 195 photos were used to produce a point cloud model (Fig. 5). The result was a 144 MB file (.psz). For later use, a file (.obj), 10.9 MB in size, and a file (.jpg) of 5.89 MB were exported.

| PC specs | |
|---|---|
| Company | DELL |
| Model | Optiplex 980 |
| CPU | Intel i7 870@ 2.93 GHz |
| GPU | Nvidia Quadro FX 580 |
| RAM | 16 GB |
| OS | Windows 7 |

*Table 3. PC Specs.*

| Process in Agisoft Photoscan | | |
|---|---|---|
| WORKFLOW | | EST.TIME |
| Align Photos (195 Photos) | | 130 mins |
| Accuracy | High | |
| Pair Selection | Disabled | |
| Advanced Settings | Default Values | |
| Point Cloud Output | 99,871 points | |
| **Build Dense Cloud** | | 60 mins |
| Quality | Medium | |
| Depth Filtering | Aggressive | |
| Dense Point Cloud Output | 10,990,384 points | |
| **Build Mesh** | | 90 mins |
| Surface Type | Arbitrary | |
| Source Data | Source Data | |
| Face Count | Medium | |
| Interpolation | Disabled | |
| Mesh Output | 169,515 faces | |
| **Build Texture** | | 4 mins |
| Mapping Mode | Generic | |
| Blending Mode | Mosaic | |
| Texture Size / Count | 6,000 × 1 | |

*Table 4. Time per Workflow stage in Agisoft.*

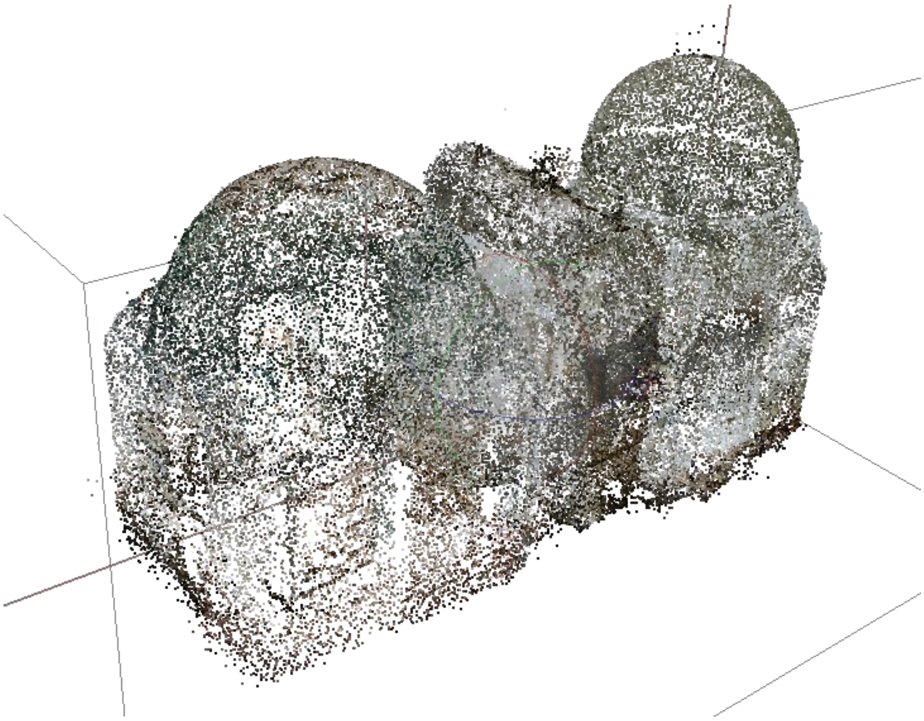
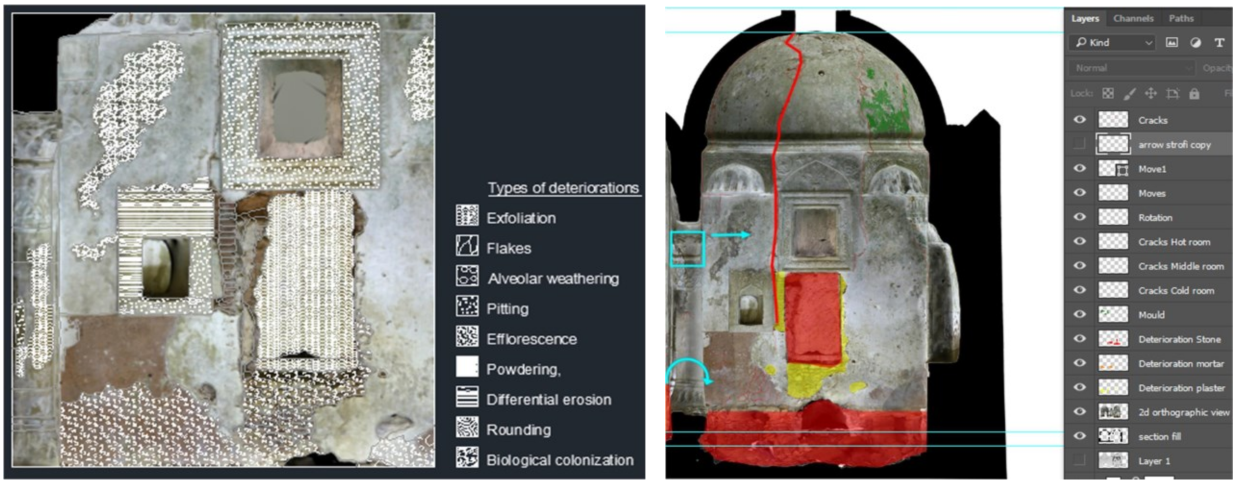


*Fig. 5. Point Cloud Model.*

**Creation of 2D documentation drawings**

The (.obj) file that was produced by Agisoft Photoscan, was inserted to 3Ds Max and the unnecessary geometry was cleaned. 2D orthographic views of all the interior faces of the building and the resonance were extracted through sections made in the model. The images that were produced were subsequently used as backgrounds for recording the deteriorations.

Two procedures were used to create 2D deterioration visualizations: 1) the first one (vector) involved the production of (.dwg) drawings through Autodesk Autocad (common process), where the 2D interior facades were imported as a background, and the layers of the deteriorations were designed using the appropriate hatches (Fig. 6a). 2) the second procedure (raster), focused on the same recording by importing the backgrounds in Adobe Photoshop and processing the visualization of the deteriorations layering separately (Fig. 6b).




*a* *b*

*Fig. 6. 2D deterioration visualizations: a) Autodesk Autocad, b) Adobe Photoshop.*

## Creation of 3D documentation

In order to create a 3D display of the building's deterioration, Photoshop was used in its 3D environment. The 3D documentation model can be created with two different ways that are presented next (Table 5).

After the Agisoft Photoscan (.obj) file was imported in Photoshop, the following steps took place:

<table>
<tr><th>2D documentation drawing to 3D</th><th>Direct 3D documentation</th></tr>
<tr><td colspan="2">Process</td></tr>
<tr><td colspan="2">1. The material of the model was replaced by the (.jpg) file which was exported as a texture file from Agisoft.</td></tr>
<tr><td colspan="2">2. The texture (.psb) file was edited with added layers in order to store changes made on the texture of the (.obj) file</td></tr>
<tr><td>3. Returning at the .obj file, the camera was aligned to the desirable section plane in order to view the same internal views of the model as the 2D drawings</td><td rowspan="3">3.Direct documentation on 3D model using photoshop tools, even in a VR environment.</td></tr>
<tr><td>4. The desired 2D documentation drawing was imported and placed relative to the camera view</td></tr>
<tr><td>5. The different layers with the deteriorations were “merged down” in order to project the damages on the 3D model material</td></tr>
<tr><td colspan="2">Advantages</td></tr>
<tr><td>Fast transfer to a 3D model of already produced 2D drawings</td><td>freedom of movement and focus, plus being able to approach very close points of the monument which the physical space requires equipment</td></tr>
<tr><td colspan="2">Disadvantages</td></tr>
<tr><td>Low accuracy of positioning 2D drawings over 3D model</td><td rowspan="2">Depending on the quality of the model</td></tr>
<tr><td>Distortion due to projecting on 3D objects. (eg dome)</td></tr>
</table>

*Table 5. Process, Advantages and Disadvantages of 3D documentation Methods.*

The same procedure can be followed for every different deterioration. The final result (Fig. 7), which includes all the deteriorations, is one .psd file for the 3D model and one (.psb) file relevant to textures with all deteriorations on layers. Inside the Photoshop 3D environment, one can browse the model and observe all the desired deteriorations by turning on/off the layers from the texture file (.psb).

*Fig. 7. The final result in the Photoshop 3D environment.*

**Sharing – Internet applications**

There are a large number of free web applications for viewing 3D models in WebGL. This research utilizes the Sketchfab platform (www.sketchfab.com) due to its simplicity, speed and ease in changing textures inside the platform, but also because it offers the ability to view the 3D model in VR mode, using cheap viewers or expensive VR headsets. The different deteriorations, which are stored as .jpg files through the .psb texture file, can be uploaded on the 3D model inside Sketchfab, under the Materials tab in 3D Settings. By switching between different .jpg files as textures in the materials, one is able to navigate through the different deteriorations inside Sketchfab's 3D model. The final models are available at the following links:

https://skfb.ly/UMvP, https://skfb.ly/UZqE

## Issues

During the whole process a number of issues arose. When editing in Photoshop 3D the bump of the space does not allow for the complete matching of the two-dimensional with the three-dimensional backgrounds and creates some losses and deformations of the final visualization of the deteriorations. These deformations are intensified in the case of study by the geometry of the hemispheric domes and generally the convex surfaces of the monument. Also, the fact that the building is housed by domes, has created overlaps of deterioration visualization during the implementation of the "Merge Down" command, since parts of the dome in the reflected ceiling plan coincide with parts of the dome on the internal aspects. The result was the display of unnecessary information and double lines.

## Evaluation and Future Work

This method proved to be a fast, low cost and flexible technique for documenting and visualizing deterioration of monuments in a 3D environment.

Documentation in both Photoshop 2D and 3D environments is offering for sketches and promising to be an ideal solution for incorporation of raster documentations like for example these of remote sensing methods.

The process suggested in this paper offers a valuable visualization tool for a non-pervasive study of historical monuments and their different kinds of deteriorations. As a tool helps researchers stay focused in the overall perception of the condition of a monument, being able to incorporate drawings, information or even notes from several specialties of professionals.

Future work may:

- incorporate in the suggested workflow the 3DHOP (3D Heritage Online Presenter) framework for the creation of interactive Web presentations of high-resolution 3D models.
- examine the success of incorporating of remote sensing documentation in 3D model
- be recording and analyzing directly on the 3D model using VR technologies such as VIVE (Fig. 8) as well as recording and analyzing in situ using AR technologies.

*Fig. 8. Future Work*

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# Structure from Motion as a tool for documenting barge wrecks in the event of looting by treasure divers and threats from a newly immigrated species, the quagga mussel.

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**Abstract:** In the 18th and 19th centuries, wooden barges, so-called "Kaffenkähne", were particularly essential for the transport of building materials, food and other goods within the Mark Brandenburg. The large transport barges are also an integral part of the contemporary cityscape of Berlin. Some of the few well-preserved witnesses of the Wilhelminian era or "Gründerzeit" are now lying on the bottom of lakes and rivers. At least ten such boats are located in the Werbellinsee in the district of Barnim in Brandenburg. Since 2007, the wrecks have been documented and researched by the registered association Kaffenkahn e.V., which consists of sports divers, archaeologists, research divers and interested laypersons.

In the last ten years, especially those wrecks have been systematically documented which lie in a depth of up to 25 m, and are therefore easily accessible for divers. In particular, the application of the "Structure from Motion" (SfM) method and the use of vertical photographs makes the massive and rapid changes to the wrecks visible and traceable. On the one hand, these changes can be attributed to a changed ecosystem due to immigrant species. On the other hand, looting was noted, which was rarely noticed before the systematic documentation, and could only be reported to the responsible authorities in individual cases. Using the example of the so-called "Ziegelwrack", the importance of regular monitoring is shown in order to document the natural and anthropogenically influenced decay of the historic transport barges. The results of our monitoring in the years from 2012 to 2019 have shown that the physical structure has already changed dramatically over the past seven years of observation. In addition to the loss of individual components, such as frames or planks, the theft of bricks, which are part of the cargo, can be observed. Furthermore, the entire wreck is overgrown with the newly immigrated species quagga mussel, which has a strong impact on the appearance and decay process of the boat.

***Keywords:*** *transport barges—Structure from Motion—monitoring—looting—quagga mussel*

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## Introduction

The Werbellinsee (Fig. 1) is located about 60 km northeast of Berlin, in the Brandenburg district Barnim and is part of the Schorfheide-Chorin Biosphere Reserve. With a length of about 10 km, a maximum width of 1.3 km and an area of 785.92 ha, it is one of the largest lakes in Brandenburg (Zühlke, 1981, p. 46). At least since the 18th century, the region around the Werbellinsee experienced an economic boom through the exploitation and transport of building materials such as wood, field stones, bricks or clay. Easy transfer by boat was made possible mainly by the expansion of the Finow Canal and the Werbellin Canal (Zühlke, 1981, pp. 119f; Meyer, 1994, p. 100; Uhlemann, 1998, p. 439). Through the Werbellin Canal, the lake is connected to the Finow Canal and the Oder-Havel Canal, along which a boat can sail to the North and Baltic Seas, or in the opposite direction to Berlin. The significance of the Kaffenkahn as the most important and cost-effective means of transport for the emerging Berlin of the Wilhelminian era is clearly demonstrated by the motto "Berlin ist aus dem Kahn gebaut" (Berlin is built from the barge) (Polandt, 1987, p. 20; Polandt and Menzel, 1989, p. 51).

*Fig. 1. Aerial view of the Werbellinsee, photographed from southwest to northeast (© M. Reinfeld).*

### The Kaffenkähne and the registered association Kaffenkahn e.V.

For years, local divers have observed the constant disintegration of the wrecks in the Werbellinsee. In 2007, they decided to form an association for the protection of these important cultural legacies. Since then, the association "Kaffenkahn e.V." has been committed to researching, preserving and protecting the barges in the Werbellinsee. In order to educate themselves historically and archaeologically, and to meet the requirements of the Monument Protection Act ("Denkmalschutz-gesetz"), archaeologists were invited to work with the association. The consortium of historically interested sport divers, archaeologists and research divers soon resulted in the first underwater archaeological courses and smaller projects, which served the further training of the team members and the documentation of the wrecks (Fig. 2). The voluntary work was approved and supported by the Brandenburgisches Landesamt für Denkmalpflege und Archäologisches Landesmuseum (BLDAM) (Knepel, 2010, p. 106; Reinfeld, 2010, pp. 72f; Reinfeld, 2014, pp. 17–20; Reinfeld, 2018, p. 470f).

*Fig. 2. Lecture during an "Underwater Cultural Heritage Discovery Course" for sport divers at Werbellinsee (© Wilfried Kroneder).*

A documentation of all Kaffenkähne known in the Werbellinsee is necessary in order to be able to differentiate between several types of barges, and to work out special features. The transport vessels differ essentially in their range, size and their technical construction because they were designed specifically to suit the needs of the skipper and the cargo to be carried. Other type variations resulted from local construction traditions or adjustments that had to be made due to the routes taken (Polandt and Menzel, 1989, pp. 52f; Sohn, 2013, pp. 23–35). In the middle of the 19$^{th}$ century, the so-called "Finowmaß" (Polandt and Menzel, 1989, p. 56; Uhlemann, 1998, p. 440) was implemented. This is a measurement for boats that was introduced specifically for the Finow Canal and the vessels that navigated it. The barges in the Werbellinsee had a maximum length of 40.20 m, a maximum width of 4.6 m, a draft of up to 1.4 m, and a carrying capacity of up to 170 t in order to allow them to pass through the channels and locks of the Finow Canal.

The wooden transport barges were built mainly from pine or spruce, with oak used for particularly stressed components. Depending on the conditions of the water, the barges could be sailed, hauled or punted. They were flat-bottomed and the stem and stern were both curved upwards and bent inwards, whereby the typical ends were formed. This shape facilitated landing on the shore. In addition, the high stem was an important aid in navigation (Fig. 3). From the stern, the skipper navigated his barge with a huge rudder, and the aid of a tip attached to the bow, the so-called “Kaffenspitze”, served as a bearing when he could no longer see the barge’s actual bow due to the high stacked cargo. In addition, a massive mast step that could hold a mast more than 20 m high was located in the front third of the boat. The skipper and his family were housed in a simply furnished cabin in the stern (Fig. 4) (Polandt and Menzel, 1989, pp. 53f, 58; Teubert, 191, p. 272, Sohn, 2013, pp. 36–54). The cabins of the Kaffenkähne are often no longer preserved. They were either destroyed during the accident that led to the vessel sinking, or by treasure divers in search of valuable objects.

*Fig. 3. Raised stem, to which an additional Kaffenspitze was attached (© Kai Dietterle).*

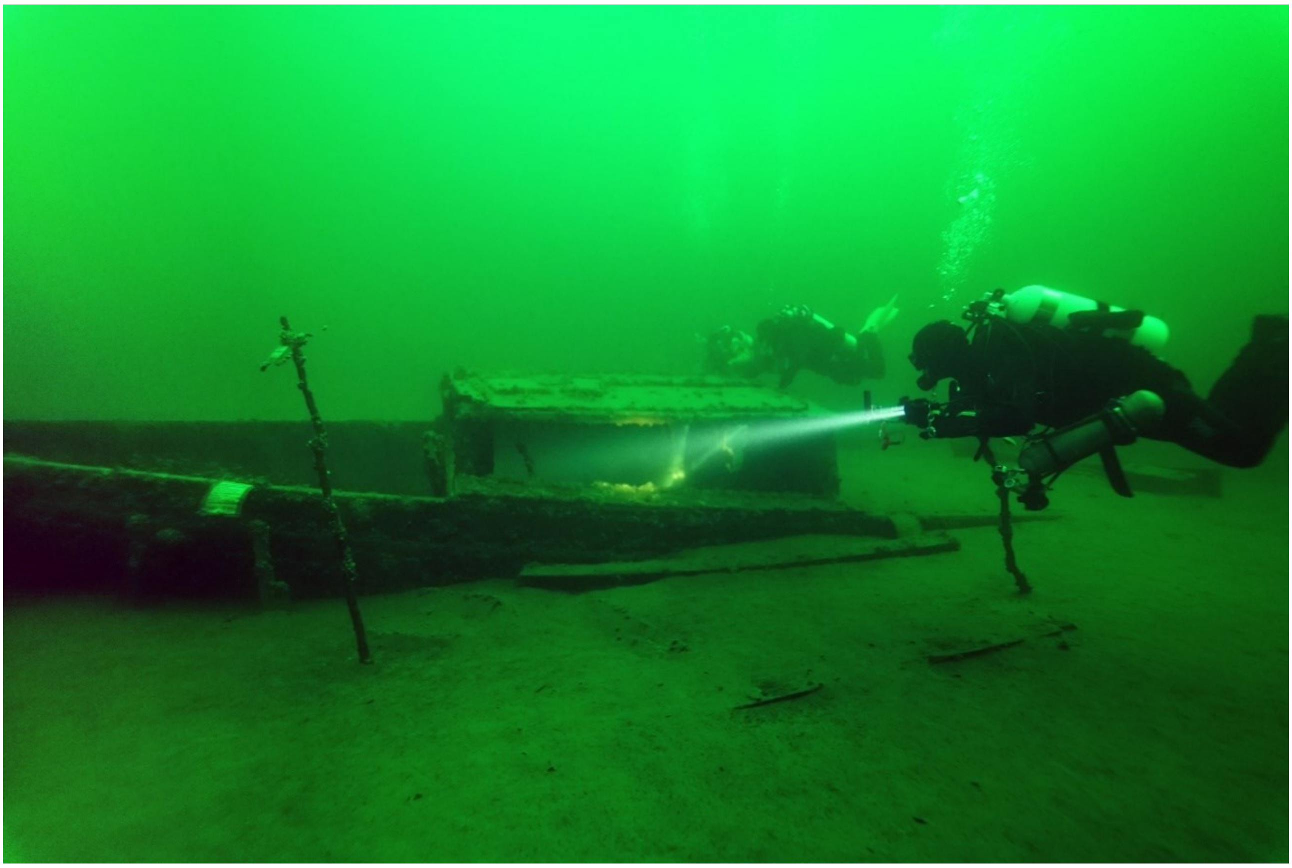

*Fig. 4. One of the rarely preserved cabins of a Kaffenkahn. The signs on the wreck should remind divers that it is an important cultural heritage site (© Kai Dietterle).*

**The first photo mosaic of a 30 m long wreck**

In addition to the traditional documentation with pencil and drawing frame, or the recording with modern sonar technology, the three-dimensional documentation of the vessels using SfM has proven successful (Fig. 5).[3] In a relatively short time, in one or two dives, an entire wreck about 30 m in length can be documented true to scale despite moderate visibility conditions. This not only enables laymen to get an impression of the appearance and size of the wrecks, it also allows quick monitoring of the condition of and potential threat to the wrecks. Another advantage is that interested sport divers can be easily introduced to the techniques of three-dimensional photography, thus making an important contribution to the documentation of the barges. Requirements are made only of the camera and the technique of photography as well as the diving skills.

A good buoyancy, that is hovering freely over the object without touching the ground or the wreck, is an essential prerequisite for good photos. Otherwise, the photos, and later the three-dimensional model, will become unusable due to sediment clouds or other objects, such as diving equipment hanging in the picture. Learning the survey techniques under water—that is the correct measuring, drawing and describing an object—require not only diving skills, but also a lot of practice, patience and extreme caution in order not to damage the barges. The difficult working conditions in the Werbellinsee, such as low temperatures, poor visibility, darkness and sometimes great depths, make it

[3] For the previous documentation work on the barges in the Werbellinsee see: Reinfeld 2010; Reinfeld 2014; Reinfeld/Knepel 2016 and Reinfeld 2018. For the application of SfM in underwater archaeology see: McCarthy et al. 2019.

necessary to adapt the underwater archaeological work to the respective season. This means that the photographic work focuses on winter and spring, as visibility under water can occasionally be up to 10 m during these months. In summer and autumn, when visibility is rarely more than 2 m, surveying and other work is preferably carried out.

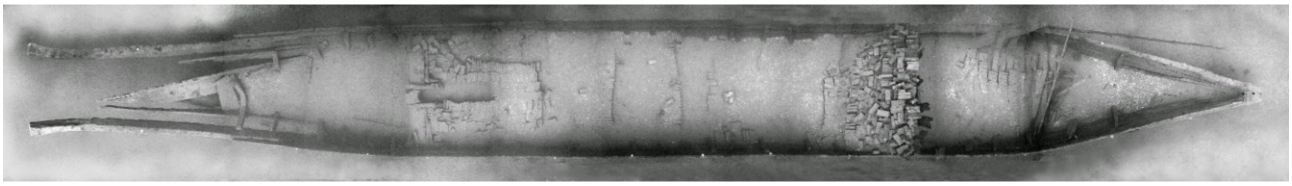

*Fig. 5. Photo mosaic of the Ziegelwrack (Brick Wreck) in 2012 (© Kaffenkahn e.V.).*

In 2012, for the first time it became possible to create a complete photo mosaic of a Kaffenkahn. At that time, it was a big step forward in the monitoring work, because the difficult conditions make it impossible to see one of the wrecks as a whole. The wreck, the "Ziegelwrack" (Brick Wreck) mentioned above, dates from the first half of the 19th century, is about 30 m long, 3.5 m wide and had a loading capacity of around 50 t. On the photo mosaic you can see individual details of the boat, such as the raised ends, the mast step, the remains of the cabin and even the individual bricks of the royal brickyard Joachimsthal, which are still neatly stacked in the boat. The elongated gap between the stacked bricks in the area of the mast chair was intentionally created in order to facilitate the raising and lowering of the mast. The bow area has already broken apart, so that individual planks protrude from the hull. In the area of the stern, at least one plank has also been pulled out from the hull. Such damage often happens when sport boats accidentally anchor in the barges because unfortunately no corresponding anchor buoys exist. The cabin in the stern has collapsed and the bricks are still nestling in a large pile against the cabin wall. It seems that the bricks were once stacked on the roof of the cabin. The brick cargo of the roof has fallen into the interior of the cabin and is still arranged in series.

Seven years later, the next step was the documentation of the vessels using SfM. The three-dimensional documentation should make it possible to look at the wreck from both the port and starboard sides, as well as from the inside. Measurements on the hull, which had previously been laboriously collected by the divers, can now be carried out on the 3D model in the shortest possible time. A comparison of the measurements of the divers and the 3D model shows their reliability. In addition, the association Kaffenkahn e.V. received information that the wreck had been looted by scuba divers. According to local divers, bricks were stolen from the wreck on a large scale and subsequently sold on eBay. The question therefore arose whether possible illicit excavations could be traced on the basis of the photographic documentation. However, there was also the possibility that any traces of illegal excavations had already become unrecognizable due to the sediment growth on the wreck.[4]

**Traces of destruction in the 3D model**

In May 2019, a two-day photo campaign was undertaken to produce a three-dimensional documentation of the wreck (Fig. 6 and 7). This resulted in around 3000 individual photos, which were

[4] The sedimentation rate of a lake depends on the supply of biomass into the lake. This means that animal and plant organisms, such as algae, sink to the bottom of the lake and form sediment layers that are several meters thick. See: Bogdal et al. 2010, pp. 561.

processed into a 3D model using the software *Agisoft PhotoScan*[5] (AgiSoft PhotoScan Professional, 2016). In order to record the wreck as completely as possible, measuring tapes were laid on the starboard and port side as a reference and orientation for the photographer and the software. The soft, monotonous sediment offers hardly any identifiable objects or contrasts that allow the software to find similar images and mesh them together, meaning that without additional reference points holes can result in the 3D model. The measuring tapes were placed at a distance of 2 m from the boat's side, so that the photographer could easily recognize both the wreck and the measuring tape despite the limited visibility. In the post-processing, the measuring tapes can simply be cut out of the model. Surprisingly, the visibility conditions deteriorated massively within a day. This not only affected the conditions for photography but also the quality of the photo model. On the first day, while the measuring tapes were being laid out, the divers enjoyed a visibility of 5 to 6 m, which made it possible to recognize both sides of the wreck. On the second day, when the photos were to be taken, the visibility was reduced to only 1 to 2 m. Now the photographer had to keep the smallest possible distance from the wreck in order to be able to take usable photos. On the one hand, this increased the number of photos. On the other hand, the risk of accidentally whirling up a sediment cloud[6] and additionally worsening the view also increased.[7]

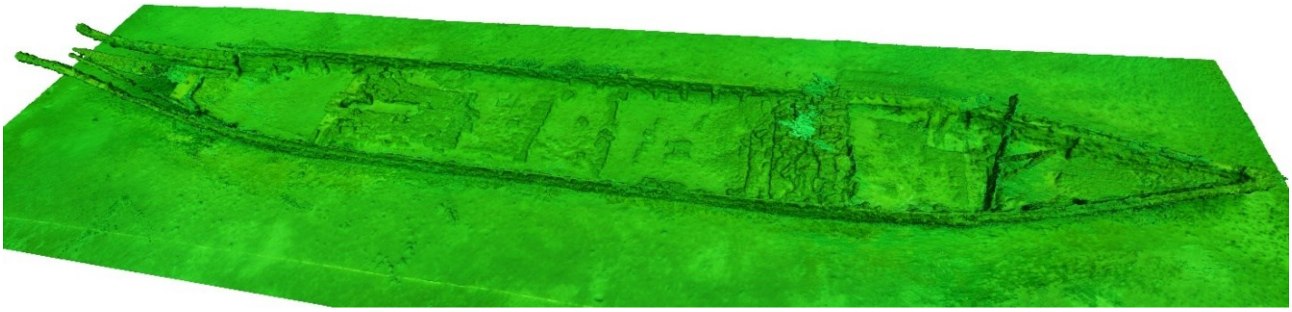

*Fig. 6. 3D model of the Ziegelwrack (Brick Wreck) in 2019 (© Kaffenkahn e.V., Bernhard Fritsch).*

*Fig. 7. Vertical image of the Ziegelwrack (Brick Wreck) in 2019 (© Kaffenkahn e.V.).*

A comparison of the two vertical photos from 2012 and 2019 (Fig. 5 and 7) reveals massive changes in the hull and in the overall appearance of the wreck. Particularly noticeable is the strong mussel growth, which affects both the wooden hull and the brick load, and even continues on the sediment. Now, the partially multi-layered mussel growth hides individual construction details and the carefully stacked bricks are difficult to detect.[8] However, holes can be identified within the rows of bricks, for

[5] https://www.agisoft.com

[6] Such a sediment cloud can be seen in Fig. 6 above the pile of bricks in the area of the cabin. The sediment cloud was accidentally whirled up by the photographer due to the poor visibility and can also be seen in the 3D model.

[7] A comparison with automated methods, for example the use of a ROV (Remotely Operated Vehicle) to create 3D models, has not yet taken place due to the high acquisition costs. In particular, this would be very useful for wrecks that lie at greater depths, i.e. from approximately 25 m.

[8] The following section will go into more detail about the extreme mussel growth that now affects all wrecks in Werbellinsee.

example in the area of the elongated gap for the mast. These holes are due to the theft of bricks. The same applies to the large pile of bricks in the area of the former cabin, which has apparently become smaller, as well as in some other places. Research on the internet trading platform eBay could not provide evidence of a sale of the bricks on the Internet, but “ancient bricks” were not uncommon as a sales object. Here, it should be emphasized that the Brick Wreck is protected as a registered monument (“Bodendenkmal”) by the Monument Protection Act of the federal state of Brandenburg, and the theft of the bricks is a criminal offense. Unfortunately, illegal underwater activities can only be detected and prosecuted in a few cases. Even public awareness of the cultural heritage under water is often insufficient. In addition, changes have been identified in the wooden hull which demonstrate the progressive decay of the boat. In the bow area, individual frames are missing and a plank has come loose in the stern. In 2012 the plank still protruded from the hull. Overall, it can be seen that the condition of the vessel has deteriorated massively over the past 7 years.

In a next step, we will try to put together old photo and video material of the brick wreck, for example from 2012 and older, into a three-dimensional model. The direct comparison of the two models will show the rapid deterioration of the ship even more clearly, both the slow destruction of the hull and the heavy fouling with mussels. Since the old photos and videos from 10 years ago were unfortunately not yet made with the aim of a three-dimensional model, the photo and video material must now be carefully searched for suitable recordings, which means a long post-processing. In view of the rapidly progressing decay, these recordings are nonetheless very important and valuable documentation. In addition, possible sources of error, which are caused by blurred or distorted images when generating the 3D model, can be better identified and corrected in this way.

**The new immigrant – the quagga mussel**

The vertical image of the Brick Wreck from 2019 (Fig. 7) looks almost blurry due to the strong mussel growth, so that individual details of the boat’s hull or the cargo are no longer recognizable. The mussel is the so-called quagga mussel (*Dreissena rostriformis bugensis*), which was first detected in Germany in 2005 and probably arrived at Werbellinsee in 2014 at the latest (Imo et al., 2010, pp. 735, 737f; Müller et al., 2016, pp. 14f). The home of the mussel is the region of the Black and Caspian Seas and the river Dnieper. Attached to the outside of the hull of ships or in their ballast water, the shell has found its way to Germany via the shipping routes through the rivers Main, Rhine, Danube and the Main-Danube Canal (Imo et al., 2010; Heiler et al. 2013, p. 56; Oldorff et al., 2018, p. 349). Due to its high reproductive rate, its high adaptability and resistance to temperatures and depths, the mussel spreads quickly. Natural predators, such as fish or ducks, can hardly stop the alien species. It colonizes both hard and soft substrates, that is wood, sediment and even living organisms, such as crayfish or native large mussels, with which it competes for food (Fig. 8 and 9). By mass reproduction and its occurrence in multi-layered colonies, the quagga mussel can change the entire ecosystem of a lake, for example, by replacing native mussel species and sponges (Imo et al., 2010, pp. 737f; Heiler et al., 2013; Müller et al., 2016, p. 13f; Oldorff et al., 2018, p. 349).

*Fig. 8. Diver at the open raised end of a Kaffenkahn that is completely overgrown with the quagga mussel (© Herbert Frei).*

*Fig. 9. The mussel colonizes hard and soft substrates until the entire bottom of the lake is covered (© Herbert Frei)*

For the wooden wrecks in Werbellinsee and probably all wrecks and sunken remains in other waters, the immigrant quagga mussel represents a significant threat. With its adhesive filaments, the so-called byssus, the mussel not only sits on the surface of the objects. The fine filaments penetrate into the sensitive wood structure and can damage it. In addition, the widespread growth in multi-layered colonies is a considerable weight for the wrecks. This not only speed up their progressive decay, it could also promote the further sinking of the wrecks in the sediment.[9] The question of whether climate change and increasing warming of the waters further boost the reproduction and spread of the mussel has not yet been scientifically investigated. A solution to this problem is currently not in sight. Scratching off the mussels from the wrecks, as is customary with boats and ships, is out of the question because this would destroy the sensitive wooden surface. In addition, the mussel would very likely colonize the wreck again in a short time. For archaeological work on the wrecks in the Werbellinsee and many other sunken cultural heritage sites, the advance of the immigrant species means that archaeologists have to work against time. The sunken heritage must be documented before it is completely overgrown by the quagga mussel colonies and is no longer visible or even destroyed. Only the wrecks at depths of about 25 m and below are not completely overgrown, but that too is only a matter of time.

This is why the association Kaffenkahn e.V. is trying to motivate as many sport divers as possible to take photos and films of the wrecks, so that at least a digital documentation exists before all the wrecks have disappeared under thick clumps of mussels. The three-dimensional photographic documentation using SfM is the simplest and most effective method to make a complete recording of a wreck in the shortest possible time.

## Conclusion

The Kaffenkähne in the Werbellinsee are important witnesses to the history of technology and transport, as well as the Wilhelminian era in Berlin-Brandenburg. In addition, they are listed as registered monuments under the protection of the Monument Protection Act of the federal state of Brandenburg. Documentation using SfM, which enables a quick three-dimensional recording of vessels, has now become the standard in underwater archaeological documentation. In particular, the wrecks in the Werbellinsee can only be satisfactorily documented within a short period of the year due to the difficult working conditions.

This is why the SfM method is the method of choice for fast documentation, even with laymen and voluntary sport divers. The targeted monitoring of individual wrecks, here using the example of the Brick Wreck, shows destruction and theft of parts of the cargo of the wreck. In addition, a complete overgrowth with the newly migrated quagga mussel (*Dreissena rostriformis bugensis*) was found which will probably make the wrecks disappear under thick mussel colonies within a few years. A struggle against time has begun in order to document as many cultural heritage sites under water before they are no longer visible or even destroyed.

[9] For their valuable information regarding possible damage caused by fouling with the quagga mussel we would like to thank Ms. Silke Oldorff (Landesamt für Umwelt Brandenburg and Naturschutzbund Deutschland e.V. [NABU]), Mr. Volker Krautkrämer (NABU) and Mr. Mirko Hauswirth (Bundesamt für Naturschutz [BfN]).

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Moreover, it should be mentioned that all the documentation work on the Kaffenkähne has been carried out with the help of interested sport divers, research divers and members of the association Kaffenkahn e.V. Both time and financial resources were used to support research into the wrecks. Special thanks go to Kai Dietterle, Uwe Klimek and Johannes Trockels (all Kaffenkahn e.V.). Finally, we would like to thank David Wigg-Wolf (Römisch-Germanische Kommission, Frankfurt am Main) for language editing of this contribution.

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# Possibilities of 3-D visualisation of an “Erdstall”

## A very narrow artificial cave from the Middle Ages

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***Keywords:*** *Erdstall—Lower Austria—Middle Ages—laser scan—3D photo processing*

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## Introduction

An “Erdstall” is an artificial cave. Numerous such caves have been built in the Middle Ages. The name “Erdstall” is not associated with “Stall” (= “stable”), but points to a spot (= Stelle). All of them have only one entrance and adit and the winding tunnels are very narrow. Sometimes there is an extra narrow passage built in (“Schlupf”) and in other sites small chambers are connected with the tunnel. Overall length is rarely more than 50 m. They can be found in Ireland, Cornwall, some Scottish isles, the Bretagne and Central France, southern and central Germany, Upper and Lower Austria, Moravia and Slovakia (maybe Hungary and Poland). Most probably there are multiple motives for their constructhion mixed together for now, as we can distinguish several types of ground plans, form and height of the tunnels, existence of chambers and other features. Such caverns were first investigated by the Austrian Catholic priest Lambert Karner, who in 1903 wrote a book about his results, which is still a valuable source. In Lower Austria Edith Bednarik continued these efforts, which until now have not produced a valid explanation for the motivation of those people to undertake such exhausting work. So far discussed explanations include refuge or hiding places in warfare, caverns for souls to await doomsday, empty graves for ancestors not taken with them in time of colonisation, places to celebrate a cult or religion, hiding places for members of a forbidden sect, storm shelters (as predicted for doomsday to come) and others.

## Site in Nonndorf near Raabs an der Thaya, northern Lower Austria

This tunnel was found when a 19th-century school building was adapted as modern residential home. When removing the floor layer a tunnel opened underneath. The owners immediately asked Edith Bednarik to investigate the discovery. They were so proud even to leave an entrance for future access, which will be situated in their prospective bathroom.

The tunnel is constantly sloping down to 6 m below ground surface with an average height of 1.3 m. After previous excavation it has an overall length of approx. 13 m. For the first 4 m it is mined through gabbro, a very hard plutonic rock. At the contact zone with Paragneis there is a stone-built wall maybe closing a former branching (or maybe a vertical shaft for material handling). From there the tunnel follows this zone to a point where the material obviously was not stable enough for unsupported extension. From there to the end of the tunnel it has a stone-built vault. At the intentional lower end of the vault a boulder choke closes a further (formerly existing) extension. When found, the vault had a hole in its top. From there and from the end loam with ceramics had filled the tunnel. Underneath the collapse the primary floor level is preserved with a dark loamy layer in it containing many pieces of charcoal. This helped dating the usage of the construction between 1407 and 1635 and extends underneath the collapse outside the end of the vault.

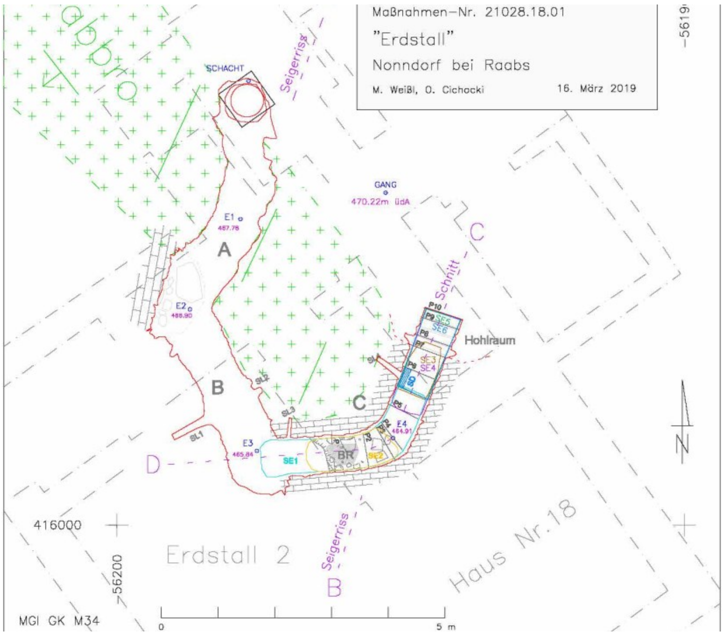


*Fig. 1. Ground view of the tunnel of Nonndorf, Lower Austria (© M. Weissl [archaeological and geological features], B. Groiss [ground plan])*

A total station was used for marking fix points, for documentation of changes in direction of the tunnel and all other dimensions. Photographic documentation shows details and progress of the excavation.

For 3D visualisation, which was very challenging because of the narrow tunnel and the many details we cooperated with Fa. Riegl (laser scan visualisation) and LBI Wien (3D photo processing).

## 3D terrestrial laser scanning and automatic processes under difficult conditions

Since several years, terrestrial laser scanning has been used to measure above and underground structures. The demand for detailed digital 3D documentation requires suitable methods that allow the highest possible geometric resolution with the most efficient acquisition methods.

The latest developments of the terrestrial RIEGL VZ series scanners allows numerous high-resolution scans per hour and an automatic merging of point clouds, so called registration method, acquired from different scan positions even without GNSS information. Additional sensor information and a workflow matched to the respective project is required for such a registration.

For this laser scanning project a RIEGL VZ-400i scanner was used. Different sensors in addition to the laser scanning unit are on-board and will be used for highly precise automatic registration: a magnetic field compass, an IMU (Inertial Measuring Unit), a barometer, and an RTK (Real Time Kinematic) GNSS (Global Navigation Satellite System) receiver. Depending on the environment in which it is used, each individual sensor fulfils a specific task in the registration of scan positions.

A standard photo camera, calibrated to the laser scanner, can be mounted on top of the RIEGL VZ-400i. This makes it possible to add an additional RGB attribute to each point for visualization and interpretation. In respect to this project, the camera had to be dismounted due to the limited space available. Therefore, no RGB information was recorded for the point-clouds of the “Erdstall” scans.

The challenge here was the very limited space in a GNSS denied area, indoor and underground. The scan project started outdoor with RTK position information. The GNSS information was used for georeferencing of the point clouds and for the automatic registration process. For further indoor and underground scans without GNSS connection the internal IMU information’s were important to record the trajectory from one scan position to the next and overlapping areas of the scan data for the orientation and fine adjustment were absolutely necessary. The final multi station adjustment, a calculation to minimize existing errors, was done by RIEGL’s post processing software RiSCAN PRO. The implementation of external and independently surveyed control points is one of the most important steps to show the absolute and relative residuals of the project adjustment.

The result of all these steps in combination with an adapted workflow, describes a robust, fast, detailed, and highly accurate measured scan project.

*Fig. 2. RIEGL VZ-400i (© B. Groiss)*

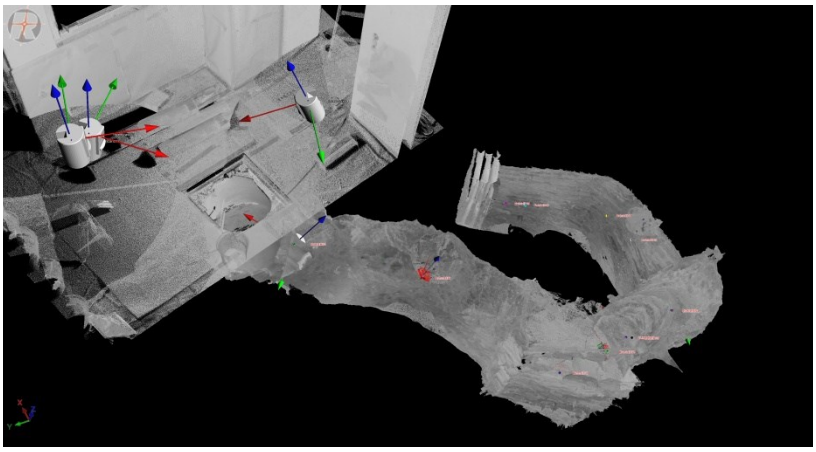

*Fig. 3. Point cloud of the “Erdstall”, colorized by reflectance- (© B. Groiss)*

## Image Based Modelling (IBM) – an alternative method for the digital documentation of narrow spaces

Another way to digitally capture our world, called Image Based Modelling (IBM), uses digital photographs from which three-dimensional surfaces are computed. In this way, a 2½D point cloud can be obtained from multiple 2D digital photos, which not only contain the high-resolution surface but also its colour information.

The first calculation step is called Structure from Motion (SfM). SfM is often referred to as a synonym for the whole process. However, this step only calculates the position of the individual images in relation to each other and generates a coarse point cloud. Only in a further step, called Multi-View Stereo (MVS), the images are processed into a dense point cloud (Verhoeven, 2016; Förstner & Wrobel, 2016). These points can now be connected to form triangular surfaces on which the corresponding section of the photo texture can then be assigned.

Digitisation by means of IBM produces a high-resolution, photorealistic, three-dimensional image of the documented surface. However, it is obvious that this can only be as good as the quality of the underlying photos. Thus, already when taking the digital photos, great care has to be taken with their depth of field, exposure and colour authenticity.

For the documentation of narrow, long stretched and strongly angled rooms, as in the example shown here, additional challenges arise. Great attention must be paid to the choice of the photo position, their regular overlapping and homogeneous illumination, as only in this way the further applied calculation steps can automatically compute the photo position and create a realistic representation of the documented surface.

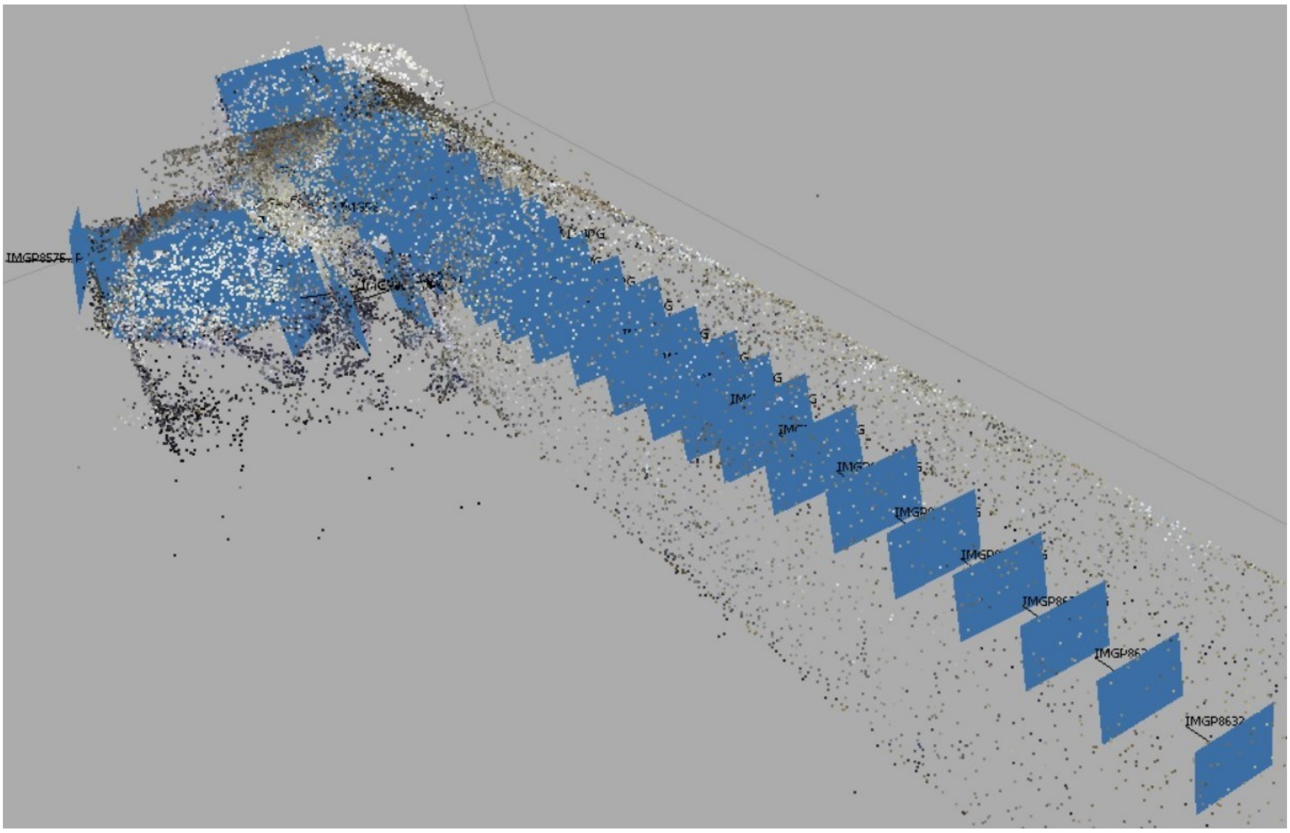

*Fig. 4. Position of several photographs in a narrow gallery to reconstruct a 3D visualisation (© M. Wallner)*

*Fig. 5: modelled surface of the tunnel and the stone-built wall ahead (© M. Wallner)*

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# What magnetic prospection, topographic mapping and archaeology can tell us about urbanism in the Mongolian steppes

## A multidisciplinary approach to Khar Khul Khaany Balgas, Khanui River Valley, Mongolia

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## Abstract

Magnetometry is a well-established geo-physical method in archaeological prospection. Conservative techniques, however, do need high investment in labour and are comparatively slow. New quantum-based sensors (i.e. so-called SQUIDs = Superconducting Quantum Interference Devices) have been innovating this methodological field through their ground breaking fastness in data collection, enormous magnetic field gradient resolution as well as the maximum of measurable magnetic information enabling depth and geometry reconstruction of the detected buried objects (magnetic inversion). Thus, the SQUID measuring system of Leibniz IPHT and Supracon AG, Jena (Linzen et al., 2007), see Fig. 1, has been successfully applied worldwide for widely different large-scale archaeological sites: be that the settlement regions of the Nasca and Palpa cultures in Peru or the *Fossa Carolina* in southern Germany, a miles long channel ordered by Charlemagne to link the Rhine-Main and the Altmuhl-Danube inland navigation systems (Linzen and Schneider, 2014). Likewise, the system has been successfully transferred to Mongolia (Bemmann et al., 2014). Here, an additional feature of the SQUID instrument was intensively used—the simultaneous recording of high-resolution topographic information via the differential GPS and the inertial unit of the motorized system. Thus, two qualitatively different maps (magnetogram and topography) are gathered with high precision in geo-reference at the same time and with high speed.

To bring the most modern standards in magnetometry to a developing country and further the scientific exchange is of high importance. At the same time, the pioneering aspect of the system which is constantly being refined through the field experience and close analysis of the data in

transdisciplinary dialogue between the physicists and archaeologists need to be emphasized. The Mongolian steppes offer an ideal ground for this endeavour with its unique cultural heritage formed amongst others by large fixed habitation sites of ancient times generally untouched by later building activities or other anthropogenic intrusions.

Thinking of the Mongolian steppes, cities do not immediately spring to mind. One rather thinks of traditional pastoral lifeways, living in yurts, sheep and above all horses. And yet, at some focal points in Mongolian history, cities played imminent roles in the steppe: first under the Uighur and most prestigiously under the Great Khans during the time of the Mongol Empire, the largest contiguous empire in World History. From the time of the 13th and 14th centuries Karakorum, the first capital of the Mongol Empire, has been a research focus of Bonn University for the past 20 years (Bemmann, Erdenebat, and Pohl, 2010). After having successfully applied the SQUID system to Karakorum in 2016 and 2017, another study of a contemporary site in order to have a comparative reference was sorely needed. Khar Khul Khaany Balgas, situated in the Khanui valley near the modern administrative centre of Erdenemandal, Arkhangai province (see Fig. 2) proved to be a perfect locality, ideally suited for SQUID-measurements as well as archaeological works. The site has never been encroached upon by later building activities, it is located in a wide flat plain on the first terrace of the river that flows nearby to the west of it, its archaeological find material and relative height of cultural levels as seen in the topography indicate that it has only been used during the old Mongol period with few settlement phases at the most. Furthermore, only few spots of the city have been touched by previous archaeologists, thus being a mostly undisturbed and an understudied site at the same time. Preparatory to the magnetic survey, to define the extent of the city and thus the area to be measured as well as to clean the city from metal waste contamination, an intensive, systematic, field walking survey was applied by the archaeological project team under the auspices of the DFG Collaborative Research Centre 1167 “Macht und Herrschaft. Premodern Configurations in Transcultural Perspective” at Bonn University in 2017. The project looks into how Mongol rulers used cities as a way of legitimizing their authority and how their authority is expressed via monuments, infrastructure and symbolic material culture in the landscape.

The SQUID instrument was applied in Khar Khul Khaany Balgas to map an area of nearly 300 hectares (3 million square metres) within 23 measurement days in June 2018. An average distance of 100 measurement line kilometres per day were driven with a cross-country car pulling the cart over the steppe area (see Fig. 1).

During the measurements the battery driven data acquisition on the cart records the magnetic data from each of the 18 SQUID sensors with a sampling frequency of 1000 Hz. Further, the differential GPS data from a Trimble® 5700 receiver is recorded with 10 Hz and the Euler angles representing the tilt of the measurement cart which is monitored by a Xsens® inertial unit is sampled with 100 Hz. These data streams result in a very high measurement point density of approximately 400 per square metre for the magnetic data and an amount of raw data of about 4 Gigabyte per day. More details about the technique of the SQUID instrument and the data post processing can be found in Linzen et al. (2007). The basis of the topographic data is a differential GPS setup which consists of one receiver mounted onto the measurement cart as rover and a second one fixed as base station. The latter was positioned on top of the north corner of the main walled enclosure (see Fig. 2). The current position of the cart has always been calculated in real time with the highest available precision (RTK fixed mode). Thus, the vertical position error was limited to a few centimetres allowing the detection of tiny altitude variations mostly caused by archaeological remains.

The Mongolian steppe with its permanent dust exposure and extreme temperature variations is a challenge for the measurement technique as well as the operators. The SQUID prospection technique, however, worked absolutely reliable. Additional expenses and skills for the liquid helium sensor cooling were required but led *a priori* to a temperature stabilisation of all sensors and a prevention of drift effects.

Through combined multidisciplinary analyses of magnetic anomalies, topographic features and the distribution of find materials gathered through the initial pedestrian survey, new insights into the city's layout, the use and function of certain building features and even down to the constructional make-up of the buildings themselves are won. These results will be highlighted through a discussion of the overall structure of the city, leading to the immanent question of whether the city has grown organically and developed from the bottom up or if we have rather indications for a top-down-planning and a supervised, thoroughly planned construction of the city. Details taken from the combined analyses will pull the scale to individual features within the city: the assumed Buddhist temple shows revealing similarities in its orientation to Karakorum's temple of the Rising Yuan, its constructional make-up with fired bricks is clearly demonstrated in the magnetic measurements and confirmed by the archaeological mapping of building materials. Further examples include the main compound, assumedly the palace area, and particular constructions on the crossroads of the major streets.

Working closely together with the local authorities in the administrative centre Erdenemandal, the new mapping of Khar Khul Khaany Balgas exerts its usefulness on different levels: first and foremost, it shows the archaeological substance in hitherto unknown detail, and second, it thus provides a definite basis for the creation of areas of cultural protection. All results will be shared with the local government to ensure that protective steps are undertaken in the near future, a fundamental necessity to preserve this important heritage for generations to come.

## Figures

*Fig. 1. The SQUID measuring system in operation nearby the main walled enclosure of Khar Khul Khaany Balgas, Mongolia. The three orange cryostates contain 18 magnetic field sensors within a scanning width of 1.5 metre (© Sven Linzen, Leibniz IPHT).*

*Fig. 2. Aerial view of the main compound of Khar Khar Khul Khaany Balgas from southwest, Erdenemandal Sum, Arkhangai Province, Mongolia (© Jan Bemmann, Bonn University).*

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## Session:
## Deploying Geographic Information System (GIS) and Remote Sensing (RS) in heritage conservation, theory and practice

Reza SHARIFI | Alireza IBRAHIMI | Marco BLOCK-BERLITZ

# Deploying Geographic Information System (GIS) and Remote Sensing (RS) in heritage conservation, theory, and practice

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***Keywords***: *Geographic Information System (GIS)—heritage conservation—decision making*

Heritage conservation and archaeology are interdisciplinary subjects; in these fields utilising the spatial data from historic sites and objects are playing a pivotal role. For heritage managers the Geodata is an essential source of information, which leads to better decision making. In this field, various techniques and methods related to Geographic Information System (GIS) and Remote Sensing are advancing in a swift-paced. Therefore the heritage practitioners need to handle with this new technology.

Theoretically, we can divide GIS implication in the field of conservation into different phases: a) Gathering data b) Data Input and Verification c) Data Storage and Database Management d) Data output and presentation and e) Data transformation, analysis and modelling. In all these fields heritage conservation can benefit, in terms of cost-benefit and task quality. GIS in the field of heritage needs to cope with other new and advanced topic such as Cloud computing, artificial intelligence and so on.

Among all the issues, in our session, we invited researchers to contribute to the frame of the below areas:

- Using GIS to integrate the spatial data, produced by the survey, historical maps, etc., from different sources attributed to the cultural heritage;
- Utilising remote sensing methods such as Satellite Imagery and Arial photography in heritage analysis, and monitoring;
- New GIS methods in heritage documentation for sharing, publishing and storing;
- Using internet-based GIS platform and techniques such as Spatial Data Infrastructure (SDI), WebGIS, mobile GIS;
- Role of GIS in decision making, especially on sensitive cases like destruction during excavation or damages due to illegal actions or conflict.

# Assessing Cultural Heritage in post-conflict Iraq

## The case of Ashur

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**Abstract:** Whilst archaeologists have worked in post-conflict zones for decades, they have rarely focused attention on how the circumstances of conflict affect their fieldwork. In recent years, ISIL attacked but could not destroy the World Heritage site of Ashur in northern Iraq. Today, the situation on the ground remains volatile in the aftermath of the war. This article will outline the challenges facing archaeologists working in post-ISIL communities in northern Iraq, using Ashur as a case study. With planning, persistence, and most importantly local co-operation, the project enjoyed success on a limited budget. Aerial reconnaissance and ground survey combined to demonstrate that the World Heritage site was significantly larger than previously recorded. The project team combined subject matter expertise with local IT experience in order to the create a customized AI algorithm using the Inception v3 model that successfully distinguished between archaeological features with an average of 87.7 % accuracy. After outlining the future of AI at Ashur, the article will conclude with a discussion of lessons learned for post-conflict archaeology in Iraq.

***Keywords:*** *post-conflict archaeology—Iraq—cultural heritage—Ashur—artificial intelligence*

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## Introduction

In ideal circumstances, modern technology allows for significant fieldwork at low-cost in almost any location on Earth. The project's initial goal was to document ISIL's destruction of Ashur in detail, including verifying reports of looting and other site modifications that ISIL might have made to prepare for the attack of coalition forces. The American School of Oriental Research's Cultural Heritage Initiative (ASOR CHI) verified reports that ISIL forces attempted to destroy the Tabira Gate, and succeeded in their destruction of the local State Board of Antiquities and Heritage (SBAH) offices, the on-site museum, and the protective cover for the Assyrian royal tombs (Danti et al., 2015), yet new field research showed that initial reports of a larger program of ISIL looting or trenching for self-defense at the site appear to relate to other mounds further south, not to Ashur itself (Danti et al., 2016). Rather than focus on the verification and falsification of past reports about ISIL's activities, this article will reflect on the myriad challenges to applying technology in post-conflict Iraq as well as solutions for projects running on smaller budgets in remote communities using Ashur as a case study.

## The Situation of Post-Conflict Ashur

Given that the World Heritage site of Ashur was liberated in late 2015, its liberation forms one of the earlier stages of the Coalition's campaign against ISIL-held territory in northern Iraq. ISIL affiliates in neighboring rural districts still conduct sporadic attacks on individuals though these attacks have decreased significantly after the October 2017 counter-terrorism operation in Hawija (Flood, 2017)[1] and the September 2019 coalition air strikes on Qanus Island (Stockton, 2019), located approximately 15 km upstream of Ashur (modern Sherqat). There are still isolated conflicts in the Khanuka mountains (15 km south of Ashur) between ISIL affiliates and Iraqi security forces (ISF) and locals report that the greater Jebel Makhmur region contains ISIL fighters driven out of Qanus Island, which prohibits night-time travel from Erbil to the region (Fig. 1). In contrast, the city of Sherqat and the archaeological site of Ashur are safe for now. The main challenges today are systemic problems of inadequate infrastructure and investment that lead to avoidable deaths such as 128 casualties from the sinking of a Mosul Ferry on March 21st, 2019 (Abdul-Ahad, 2019); or an unreported capsizing of a local ferry at Sherqat in May 2019 that ultimately killed 4 young women. They died as a result of the spring floods, yet they would have lived if the bridge over the Tigris had been completed.

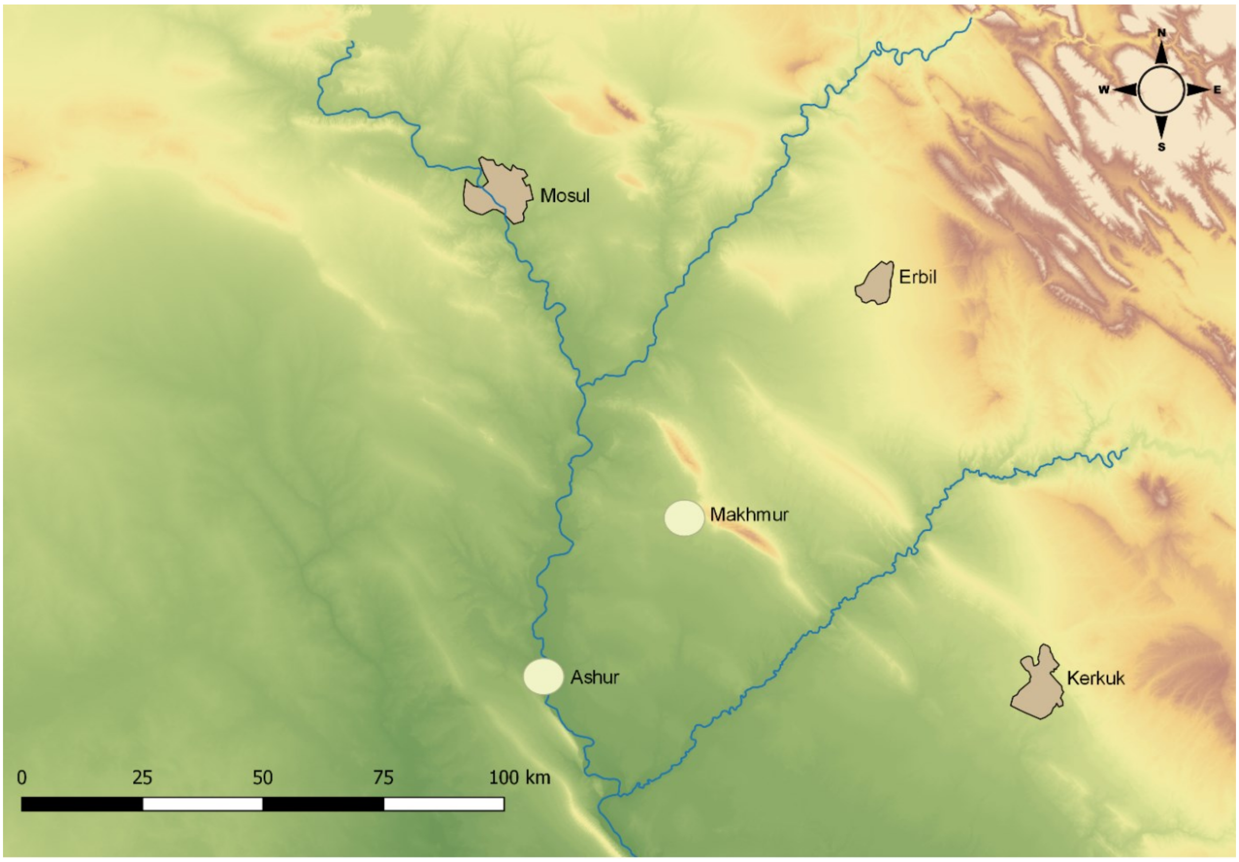


*Fig. 1. Map of Northern Iraq showing the situation of Ashur (© Tobin Hartnell).*

[1] The city of Hawija in western Kirkuk Province was the last urban stronghold of ISIL in Iraq.

Despite no reports of casualties at Ashur since late 2015, the logistics of conducting fieldwork there remain challenging. The project initially coordinated a police escort through Kirkuk Province (including Hawija District) but abandoned this approach after ISIL killed three Peshmerga on May 4th, 2019. There was an ISIL attack against Makhmur on May 10th, and a car bomb that killed four people in Kirkuk on May 26th. al-Baghdadi claimed ISIL's responsibility for an attack in Sri Lanka that same month. The Kirkuk police justifiably felt that they would become targets, if they helped the team travel through post-ISIL territory.

After contacting local and international security companies, it became clear that the cost of private security would consume all of the budget in just a few days of work. The team settled on a Sunni Arab police and military escort from Iraq's internal border at Makhmur which divides the Kurdish Region of Iraq (KRI) from the rest of the country. Thus, the project conducted a preliminary meet-and-greet with the local security and archaeology officials in Sherqat in July, and then a ground assessment of Ashur in late August, and aerial documentation of the site in early September. Post-processing continued until the 24th CHNT conference in November, and even for a few weeks afterwards.

## The Barriers to Research at Post-ISIL Ashur

During the Coalition's liberation campaign, ISIL used various small, customized UAVs (colloquially drones) to drop munitions on coalition forces threatening their positions in Mosul and other strategic places, just as Coalition forces used their own UAVs for surveillance and to project power. Given this recent history of conflict, people living in post-ISIL territory still have trauma related to the use of UAVs in civilian contexts. For this reason, the civilian use of even small UAVs in Iraq is severely restricted and virtually the entire country is one large No Fly Zone (NFZ). For the documentation of Ashur, the project needed approval of the Ministry of Culture, the local office of SBAH, and the local security forces, in this case Sunni tribesmen led by the al-Jabouri tribes. Given that the security situation in post-ISIL territory remains fluid day-to-day, the project used a hardware solution (a specialized chip) to allow for flights at Ashur rather than go through a lengthy application process for a software fix with DJI.

## Privacy in a Post-Conflict Environment

Even with local permits, SBAH continuously monitored the DJI Pro 4's daily operations. One of the primary concerns was to limit, as far as practically possible, any flight paths that went beyond the official boundaries of the World Heritage site. The territory north of the site is almost completely free of human occupation, as it consists of open land. The eastern boundary is formed by the natural course of the Tigris River. Thus, the main priority was to avoid flights over suburban districts that currently flank the western and southern sides of the site. Even though the actual fencing was stolen during the period of conflict, the line of the original BRC fence is still visible and formed the limits of the flight paths on the western side. The Wadi Zazi formed a natural boundary to the south.

## Challenges of Flying in the Summer Heat

The timing of the project placed an additional burden on data collection. Logistical delays meant that the fieldwork was undertaken over the summer, when Ashur experienced highs between 39 and 42 °C (Accuweather, 2020). After meeting local stakeholders in July, the team originally aimed to complete two simultaneous assessments (ground and air) of the site in August. Unfortunately, mechanical problems with the drone limited the season to an in-depth ground-based assessment of the site. This assessment is notable because it was the first time that the team collected direct evidence for an Outer City of Ashur, in the form of ceramics exposed by informal excavations of the local brick factory over the last few decades. The existence of an outer city roughly doubles the previously recorded size of the site from c. 80 ha to c. 150 ha (Fig. 2). The third visit in early September conducted an intensive aerial survey that collected 11,914 photographs in 4K.

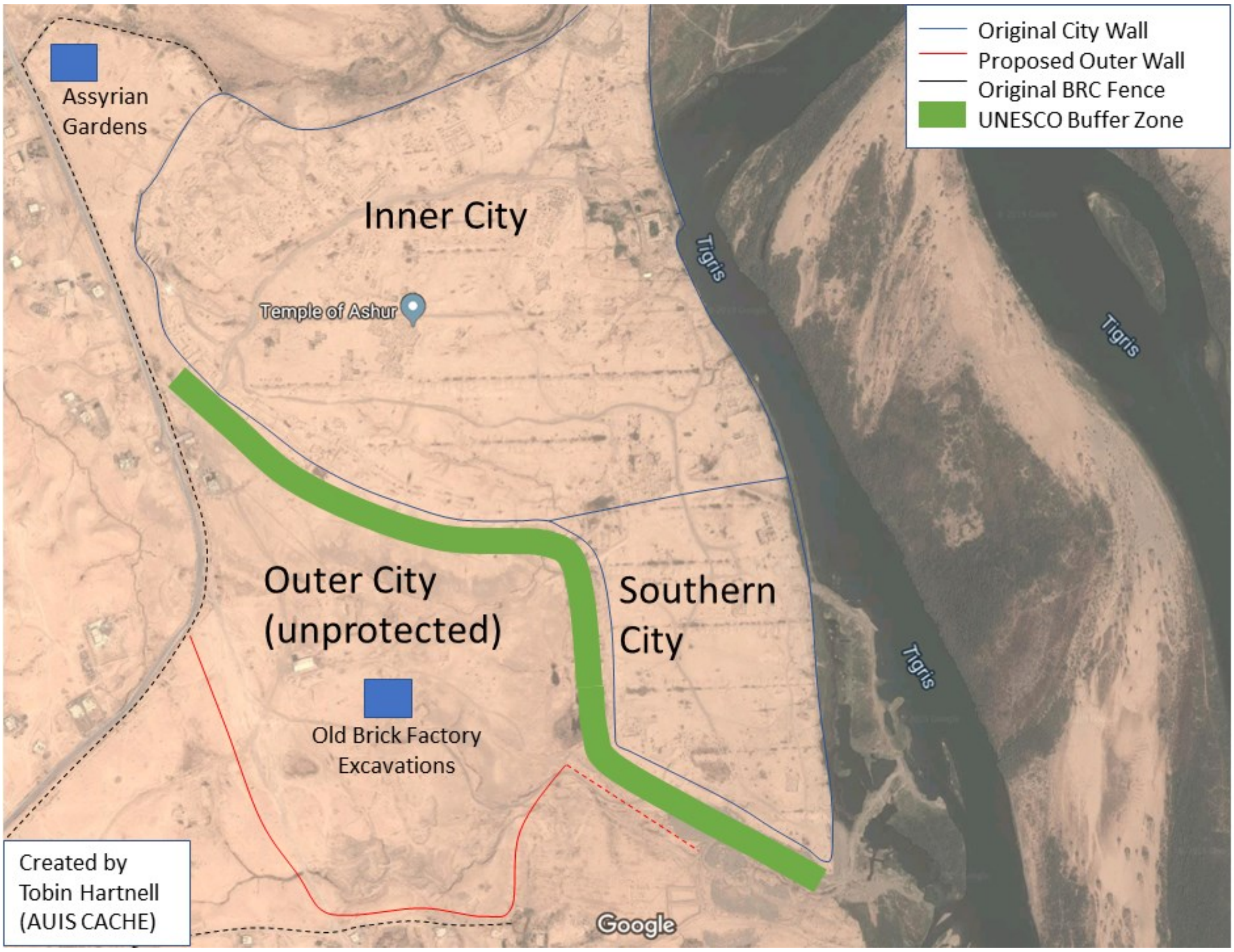


*Fig. 2. Image of the City of Ashur with the Outer City (© Tobin Hartnell, not to scale).*

Even with a mid-day break to avoid the worst of the heat, flying in early September in Iraq posed a number of environmental challenges to the fieldwork. The summer temperatures limited the sUAV's battery life and affected the operation of the iPhone and iPad mini that hosted the relevant app for planning and executing flights. Without these devices, the team would have no verification of what the drone was doing. At some point, the team lost the DJI 4 Pro in the northwestern section of the city for several minutes after the iPhone piloting the drone overheated and stopped working.

Fortunately, the sUAV initiated an auto landing sequence, and the team drove to relevant section of the buffer zone to retrieve it. From this point forward, an ice pack was a constant companion as the iPad mini used in subsequent flights would quickly overheat without it.

## Infrastructural Challenges to Research in Post-Conflict Ashur

Even after keeping the iPad cool, there were two more problems – how to recharge batteries without reliable electricity and how to communicate with the drone between flights. ISIL sympathizers had effectively stripped the electric cables from all of the site, and destroyed the local SBAH offices. The SBAH residence that served as a temporary de facto office typically ran out of electricity by 11 am, which would effectively limit recharging time to the early morning. The August visit thus spent significant time and resources on improving the electricity supply to the SBAH residence, so that it could get a larger share of electricity from Iraq’s national grid and also receive electricity from the Guard’s residence where there was a diesel generator. For the September visit, the team also greatly increased the number of batteries from four to 10. Even then, the team would constantly swap batteries whilst being cautious about battery heat.

The final technical challenge was ensuring timely communication with the sUAV in a post-war environment that lacked significant infrastructure for accessing to the Internet. Wireless Internet was the only feasible option in the field, yet many of Iraq’s 4G options are limited only to specific regions. At first, the team ran off personal hotspots from the smartphones of our SBAH partners. Eventually, the team decided on an Asiacell 4G (actually a slow 3.9 G) wireless connection that was stable but slow.

With limited access to Internet, the team had to pre-download every map, application, and online resource before going into the field every day. The limited Internet access also dictated the choice of flight software, as the Pix4D App required the drone operator to upload a significant load of data before every flight, which led to 15 to 20 minutes of downtime between each flight. The team’s drone operator decided to install Drone Deploy which requires minimal data transfer between flights and downtime was limited to 30 seconds or less between flights. Given that this included the time required to change the batteries, the process was effectively seamless.

The overall goal of the aerial flights was to collect imagery 50x to 100x more detailed than images provided by commercial satellites. By limiting the forward overlap to 65 % and the side overlap to 60 %, the team could fly at 30 m altitude over the main mound and preserve a resolution of 1 cm/pixel, whilst it could fly at 60 m altitude over the Outer City and the Buffer Zone and preserve a resolution of 2 cm/pixel. This resolution compares very well to the superannuated Google Earth imagery available for Ashur (taken before the war against ISIL), as well as more recent commercial alternatives like Planet Labs (72 cm or 120 cm/pixel depending on the image quality; Fig. 3). High-resolution processing of the imagery resulted in several 3D composites of major landmarks of Ashur (Figures 4 and 5), though the computing time to render a complete 3D model at the highest possible resolution is expected to take two weeks of processing time.

*Fig. 3. A visual comparison of Google Earth and low-altitude sUAV imagery of Ashur (© Tobin Hartnell and Adam Azad Tawfeeq).*

*Fig. 4. 3D Composite of the ziggurat, Temple of Ashur, and the destroyed on-site museum (© Adam Azad Tawfeeq).*

*Fig. 5. 3D composite of Ashur's Ziggurat (© Adam Azad Tawfeeq).*

## Creating an Artificial Intelligence Algorithm for the Ashur Project

The project's overall aim for using Artificial Intelligence (AI) was to increase efficiency and reduce the time it takes to process the large amount of data collected in the field. The team currently consists of just four people, and it had to handle over eleven thousand images. For this reason, the project trialed the use of AI as the primary means to classify the collected imagery. In terms of technology, the team's programmer used Tensorflow, a free and open-source software library developed by Google. The project later augmented Tensorflow with Keras, an open-source neural network library written in Python.

Though the project lacked significant IT resources at the office, the team included two cultural heritage experts proficient in Iraqi archaeology. The choice between supervised and unsupervised learning came down to the fact that the team could leverage its subject matter expertise (SME) to train the algorithm. Six students assisted the archaeologists in this process. A Supervised Learning Algorithm is a type of machine learning algorithm in which data or features are linked to pre-defined names or labels. Supervised learning is useful when the project has a large data set and a known output. For example, the project team pre-sorted thousands of images into categories such as mud-brick walls or excavation trenches. The input or feature is the data (the imagery) and the output matches the data to the label with varying degrees of confidence. The total cost of student labor for the AI project was less than $400 USD, whilst the other equipment and labor was donated.

### Training the Model using Transfer Learning

Simplicity of implementation was a major factor in determining the method. The main reason behind using the Inception v3 model instead of custom building an AI model is that this model is designed with more expertise and has been trained on a huge library of data from *Image net* data set that the team cannot hope to match. In more technical language, Inception v3 is a pre-trained deep convolutional neural network model that is widely used for image classification (Szegedy et al., 2015;

Valigi, 2016; Google, 2019; Milton-Barker, 2019). The Inception v3 model has been trained on the *Image net* data set and shows great accuracy.

However, the project team still made some custom modifications to the Inception v3 model to better fit the project goals and then trained the last layer of the model on the field data through the transfer learning process. The learning rate is a user-defined parameter that modifies the model based on the estimated error each time the algorithm updates the model weights. In this case, the project team set the learning rate at 0.01. The Epoch is a reference to the number of iterations the model takes training data. In this case, the model trained itself in 500 steps. Through repeated optimization of the model, the project got the desired result.

Artificial Intelligence algorithms need a sufficiently large body of data for training (typically 500 images per category). The team set the testing percentage at 10 % of the total images available to the algorithm. Thus, for the roughly 500 images used in each trial categories, the team asked the algorithm to correctly identify 100 images. As all of the project's images came from a single source, the camera attached to the DJI Phantom Pro 4, and all images shared the same settings, there was little pre-processing required for the image dataset. The major obstacle was the presence of specialized metadata, which the algorithm could not handle. The team relied on XnConvert to batch process the imagery. XnConvert allows the operator to strip the metadata from the image during the conversion process. The preferred file format was JPEG. Image preparation took less than a day, once the correct technical solution was identified. Beyond this step, the project did not need to augment the data any further. Regarding the normalization process, the Inception v3 model uses the Batch Normalization Method, which was also used in this case.

Since most of the collected images contained multiple features and unrelated items, the project preferred to use a pre-trained model which is then trained on archaeological objects instead of building a custom model. Local trials used two sets of data, each containing around 500 images. As expected, the more data fed to the model, the better the classification result. An experimental trial used images of mudbrick walls and excavation trenches of various ages and states of preservation. The challenge was that a computer would have to correctly distinguish between trenches, other topographical features, and walls even after some archaeological features have been exposed to erosion for more than a century.

## Preliminary Results of the Ashur Artificial Intelligence Project

The test consisted of 100 images chosen at random from those images not used to train the algorithm. Overall, the algorithm was successful. The model successfully identified features with an average of 87.7 % reliability, with 68 % of images having over 80 % reliability (Table 1). Of those images with a reliability rating of 80+% or greater, the algorithm correctly identified 100 % of the images. For those images with a reliability rating between 70 % and 79.99 %, the algorithm correctly identified 88.9 % of the images. The three false identifications from images with a reliability rating of 60–79.9 % seemingly derive from the nature of those images. In the first case (reliability 66 %), the image has a rectilinear feature (possibly a foundation) made of concrete. The algorithm seems to have incorrectly identified this concrete feature as a mudbrick wall. In the next two cases (78.57 % and 79.65 %), it appears that the algorithm identified old section walls as mudbrick walls (Fig. 6).

With more data and training, these false identifications can be minimized though probably never eliminated. The danger is that without subject matter experts holding significant local knowledge, the algorithm's false identifications may be accepted uncritically. For this reason, a subject matter expert should personally review those images with the lowest confidence rating to ensure the integrity of the result as well as those images that appear to be outliers based on the goals of the project.

| Percentage of Reliability | Total Images by % of certainty | False Identifications |
|---|---|---|
| 50–59.99 % | 8 | These results are too uncertain to be useful. |
| 60–69.99 % | 6 | 1 |
| 70–79.99 % | 18 | 2 |
| 80–89.99 % | 21 | 0 |
| 90–99.99 % | 47 | 0 |

*Table 1. Summary of the results of the Artificial Intelligence Algorithm.*

*Fig. 6. A sample of problematic images from the AI study (©Tobin Hartnell and Adam Azad Tawfeeq).*

## The Future of Artificial Intelligence at Ashur

Archaeological sites are complex and each image typically contains more than one feature. The current iteration of the Artificial Intelligence project has identified what subject matter experts considered the main feature in the image, yet it is possible to delineate specific features within the image before training the model. For example, a trained analyst would tell the computer which part of the image contained a wall and which part contained a road. By specifically focusing only on the feature itself, the algorithm will become more reliable even when identifying features that exhibit vegetation growth or suffered significant erosion. A second-generation Artificial Intelligence algorithm is currently under construction and should be ready for the 25th CHNT conference in Vienna.

On reflection, working in post-conflict Iraq requires flexibility to overcome the numerous environmental and social challenges facing the project. This year's work employed six students, two foreign archaeologists, three local archaeologists, and an IT professional for only $3500 USD. On top of that, transport, housing, and security for the fieldwork at Ashur was donated to the project free of charge. With significant planning and the right support, important fieldwork on a limited budget is possible even in a post-conflict environment. For this reason, the team would like to finish this article by thanking all the people who contributed to making the preliminary work at Ashur a success.[2]

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# Identifying archaeological potential in alluvial environments

## An evaluation of remote sensing techniques at the River Lugg, Herefordshire, UK

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***Keywords:*** *LiDAR—Multispectral—SUAS—Alluvial Landscapes—Digital Elevation Model*

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## Introduction

The successful application of archaeological prospection techniques to complex geomorphological areas, such as alluvial environments, remains a significant challenge for heritage practitioners, particularly in advance of sand and gravel extraction activity which is also common in these areas. This is primarily because large parts of these landscapes are covered with a thick layer (or layers) of fine-grained alluvium that prevents the effective visualisation of any archaeological remains that may be deeply buried. However, such settings provide attractive locations for archaeological activity and when remains are located, they can be exceptionally well preserved. Moreover, the valley floor contains an assemblage of landforms such as paleochannels, terraces and gravel islands which record of the evolution of the river system (Brown, 1997). These geomorphological features often contain important ecofactual and archaeological remains and understanding their location, morphology and sedimentary sequences is important for predicting archaeological potential. Thus, whilst the geoarchaeological investigation of alluvial landscapes is well established (e.g. Needham and Macklin, 1992; Howard, Macklin, and Passmore, 2003), the application of appropriate remote sensing technologies to determine archaeological potential within complex depositional environments requires more research (Challis and Howard, 2006).

## Remote sensing and complex geomorphology

The use of LiDAR has been highly effective at mapping geomorphological features that are expressed as extant topographic variation (Carey et al., 2006; Challis, Kincey and Howard, 2009; Stein et al., 2017). However, as alluvial deposition can blanket important geomorphological features, and subsequent ploughing can also smooth out topography, the identification of geomorphological features can be problematic. The use of complementary information from geoarchaeological coring/test-pitting goes a long way towards reducing this, but normally requires the use of costly intrusive ground investigations. Geophysical survey methods and deposit modelling from pre-existing geotechnical datasets can provide a non-intrusive means of identifying features that are not expressed topographically, but there has been relatively limited consideration of how other remote sensing techniques can be deployed to assist in this regard.

Multispectral sensors co-collect imagery from discrete (narrow) wavelength ranges over parts of the electromagnetic spectrum, whereas panchromatic aerial imagery is sensitive to a broad spectral range covering the visible part of the spectrum (Beck, 2011, p. 88). This can be advantageous as crop stress and vigour variations that may relate to subsurface archaeological/geomorphological features, are sometimes better expressed in non-visible wavelengths (e.g. Powlesland, Lyall and, Donoghue, 1997). Though archaeological applications of satellite and airborne multispectral sensors are not new, there has been a relatively limited uptake of this technology in alluvial environments. This is largely due to the cost of deploying systems that can provide suitable spatial resolution for the definition of individual features. However, with the development of lightweight multispectral sensors that can be mounted on Small Unmanned Aerial Systems (SUAS), imagery can now be provided at very high spatial resolution and relatively low cost. Although the spectral resolution of these sensors is low, being limited to portions of the visible and near-infrared parts of the spectrum, they have potential to assist in the analysis of surface landform assemblages. Moreover, recent research has also shown enormous potential for archaeological applications of this technology in less complex geomorphological environments (Colomina and Molina, 2014; Themistocleous et al., 2015; Agudo et al., 2018; Moriarty et al., 2018).

In addition to multispectral sensors, low-cost devices that measure omitted radiation of the ground in the thermal region of the electromagnetic spectrum can also be mounted on SUAS. These have also demonstrated a great deal of potential for archaeological research (e.g. Casana et al., 2014, 2017; Agudo et al., 2018; Šedina, Housarová, and Raeva, 2019), but have yet to be deployed in a targeted manner to investigate complex geomorphological areas. However, as the emissivity and temperature of the ground is dependent on its bulk composition, as opposed to its surface characteristics, thermal imagery has potential to provide information about the subsurface (Thakur et al., 2016).

## The Lower Lugg Valley, Hereford, UK

This paper will present a case study from the Lower Lugg Valley in Herefordshire, where the capability of SUAS mounted multispectral and thermal sensors to contribute an increased understanding of complex alluvial environments has been investigated. As use of a SUAS platform also enables the production of elevation models through Structure from Motion (SfM) photogrammetry, a comparison with LiDAR data (freely available from the UK Environment Agency) is also considered.

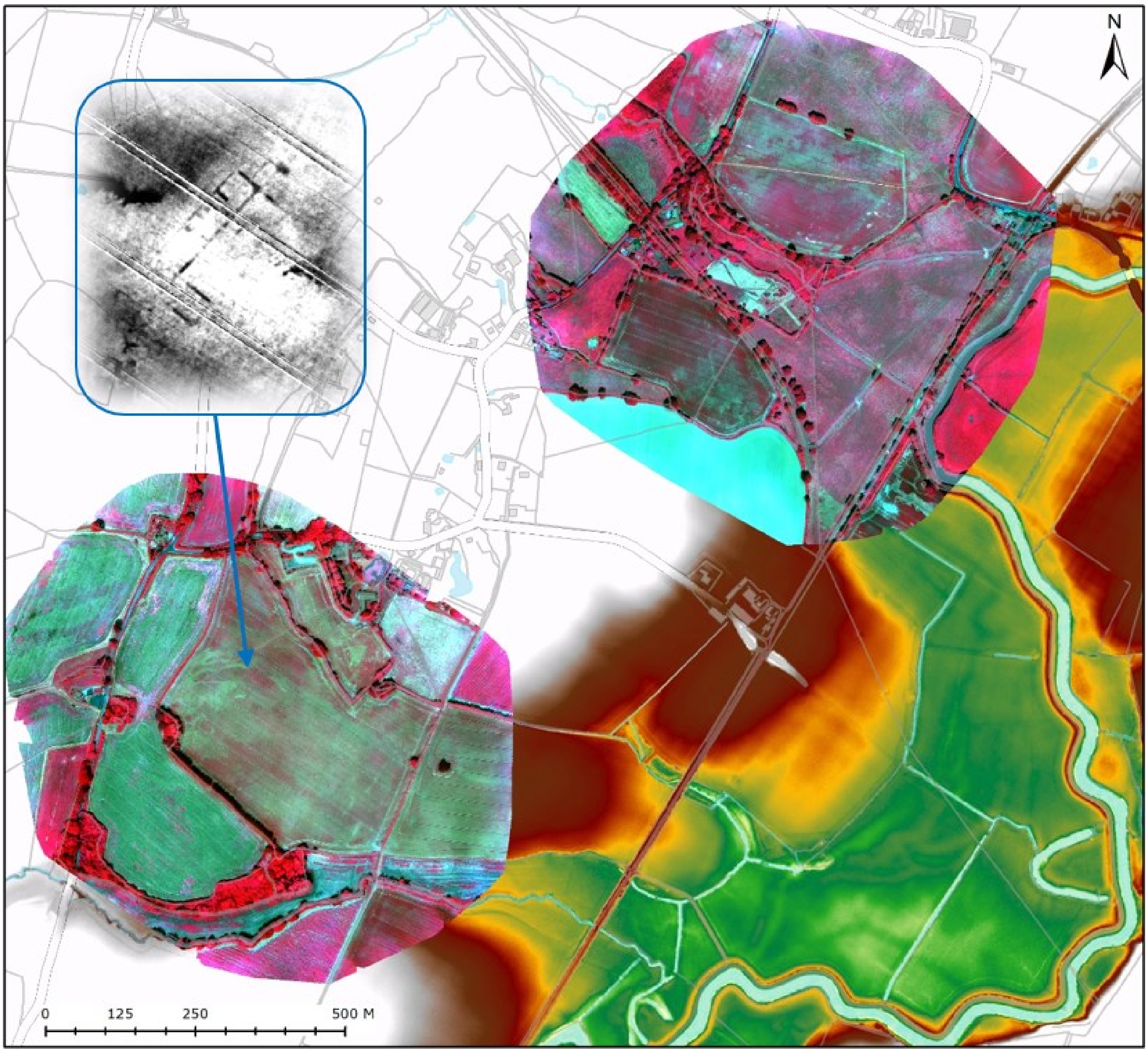


*Fig. 1. LiDAR DTM constrained to 2–9 m (aOD), with false colour composite imagery (R = NIR, G = Red, B = Green) overlain and a detailed view of Romano-British Villa (inset; greyscale NDVI). Contains © Environment Agency LiDAR (2015) and Ordnance Survey data © Crown copyright and database rights (2018) Reference number: 100025252.*

Preliminary results have shown that the high spatial resolution of the SUAS mounted sensors enables the clear visualisation of small-scale individual archaeological features (Fig. 1). It has also established that various alluvial landforms such as paleochannels could also be identified, although these can sometimes be hard to define, emphasising the importance of topography when understanding their morphology. In addition, broad trends may also indicate variation within the sub-surface deposits. Thus, although it is not possible achieve the same area coverage as many LiDAR datasets, targeted application of complementary techniques can assist their interpretation. Despite this, this evaluation has also shown that ground-based sediment sampling, reconstructing the sediment sequences of the valley system and examining their relationship to near surface and sub-surface sediment, are often necessary to provide an increased understanding of subsurface sediment architectures. However, through such a combined approach, it is possible to make predictions regarding archaeological potential.

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# Lifeguard for large-scale geophysical surveys

## Automated anomaly-analysis of geomagnetic data using open-source GIS-tools

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***Keywords:*** *Geomagnetic Survey—Automated Processing—Classification—GIS—Open-Source*

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### Drowning in data

Geophysical surveys rank among the most important and effective technologies for archaeological investigation and cultural heritage management. The performance of measuring systems has drastically increased in recent years: While earlier surveys using rather slow single-sensor systems produced a relatively manageable amount of data of about 0.5 ha per day under favorable conditions (Cf. Aitken, 1974, pp. 234f), today a single person using one of the increasingly popular multisensor systems can cover 15 or more hectares per day, generating approximately one million readings per hectare plus geodetic datum. While this growing capacity allows for applying this type of survey for landscape-scale research objectives effectively, the tremendous amount of data exceeds the capacities of manual interpretation by far, especially since time and resources are often devoted more willingly to data collection than to office work (Cf. Aitken, 1974, pp. 234f). The German Archaeological Institute (DAI) operates two 16-sensor fluxgate-magnetometer rigs, to date resulting in overall coverages of up to 10 km² at sites like, e.g., Avebury or the princely site of Vix at Mont Lassois. Beside the unaffordable time requirement, manual interpretative vectorization is always subjective and rather inaccurate. To analyze and interpret this amount of data in a reproducible and more efficient way, new tools and workflows had to be developed.

### Finding the edges

Interpreting vast amounts of data does not represent an entirely new problem in remote sensing applications. Satellites cover far more ground than any other survey technique and it comes as no surprise that a number of tools have been designed to classify satellite images and support their interpretation (Cf. 'Image classification', 2018). In the case of traditional geomagnetic data, the interpretation is somewhat hampered by the fact that only the magnetic flux density is recorded. This, apart from being affected by past anthropogenic and geological activities, can also be distorted by a number of other factors, including the location on the globe, the direction of measurement as well as disturbances caused by the vehicle or person moving the instrument.

*Fig. 1. Sensys MX V2 and V3 multisensor magnetometers in front of Mont Lassois. (© DAI/E. Runge)*

Archaeological features cannot easily be distinguished from these other anomalies; simply vectorizing the resulting noisy data automatically based on differences between cell-values would create a muddled polygon-cluster, each polygon representing a single value. Hence, the original measurement readings have to be reclassified, e.g., into a binary raster containing only the number 1 coding values above a certain threshold and 0 coding values below. The vectorization tool of choice can then be used to trace the edge between 1 and 0 resulting in polygon-features. Since the threshold value can be set down to 1/10 nT this method is far more precise than any manual vectorization. Further steps in this workflow include different buffers and smoothing resulting in an accurate and detailed image.

## Going open source

The general approach to do this for geomagnetic data has been around quite a long time (Neubauer, 2001, pp. 125–129), but the actual methods were, if used at all, only implemented individually by a few computer enthusiasts. Instead of creating yet completely new and/or proprietary software, the DAI decided to make use of the tools already available in open-source GIS libraries, such as GRASS or SAGA. All necessary steps (binarization, vectorization, cleaning and smoothing) are implemented in QGIS—ready to use. In a first attempt these algorithms were applied in a sequence manually, which proved to be helpful, but also very time consuming (Goldmann, 2017). Using the QGIS graphical modeler, the DAI recently developed a Python-based script to automatize this process. The script is intended to be published in the Official python plugin repository for QGIS. Using the free, open-source software QGIS and the widespread scripting language Python are meant to facilitate the dissemination and ease of use of this tool.

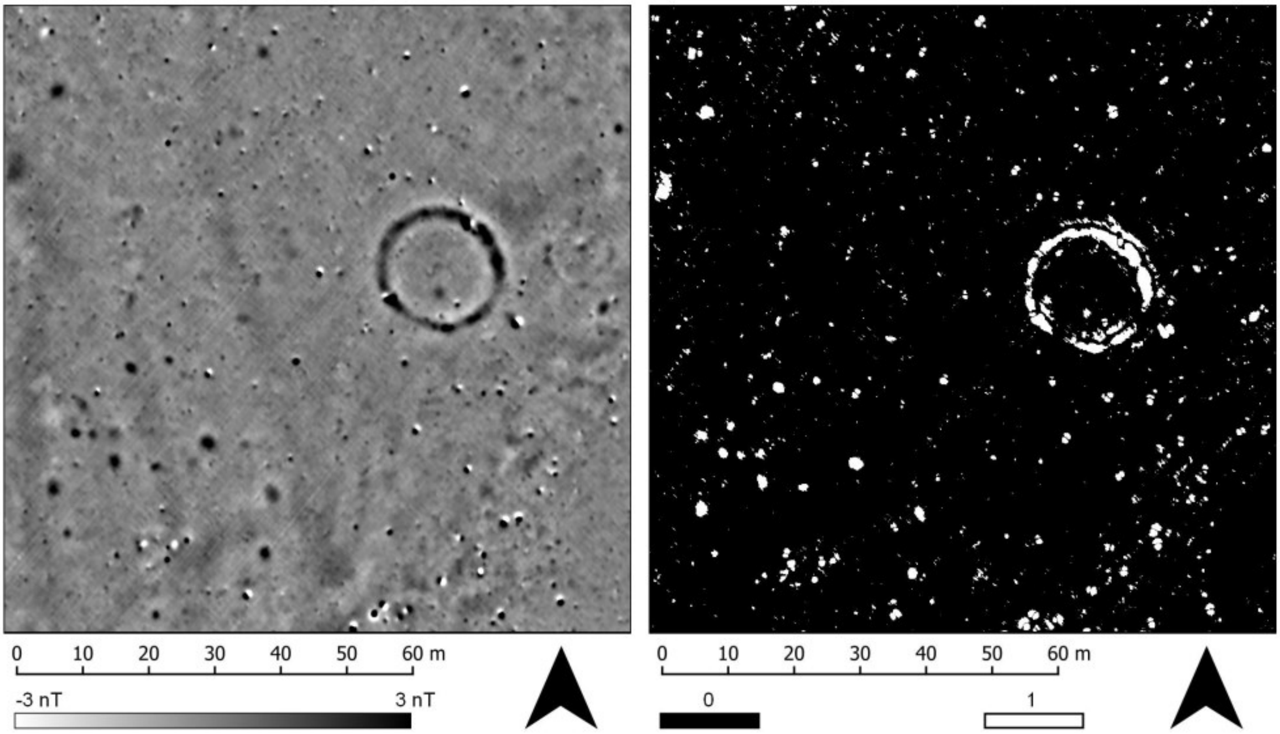


*Fig. 2. From left to right: a) Original magnetogram. b) Binary raster created using a threshold of 2 nT. (© DAI/L. Goldmann)*

## Applying terrain analyses for geomagnetic data

As mentioned above, raw geomagnetic data do not provide much potential for classification. However, there are certain characteristics, allowing for distinguishing anomalies, which can be statistically analyzed and used for automatic classification. Frequently, automatic recognition of dipole-features, mainly representing modern iron debris, would be a great help for analysts. Dipole-features are marked by a negative minimum paired with a positive maximum, which are, however, often not directly adjacent. Directly vectorizing such dipoles results in two separate polygons, which do not lend themselves to statistical analysis. Therefore, single features are created through buffering and merging these parts. The rapid change from high to low values is reflected in different terrain parameters, such as slope or terrain ruggedness index (TRI), all of which can be calculated in any GIS. Especially the TRI proved to be useful when screening dipoles from other features. An analysis of certain terrain parameters, therefore, was included in the plugin. The respective values are added to the attribute table of the vectorized features and can be used for a query-based classification (see Fig. 3b)

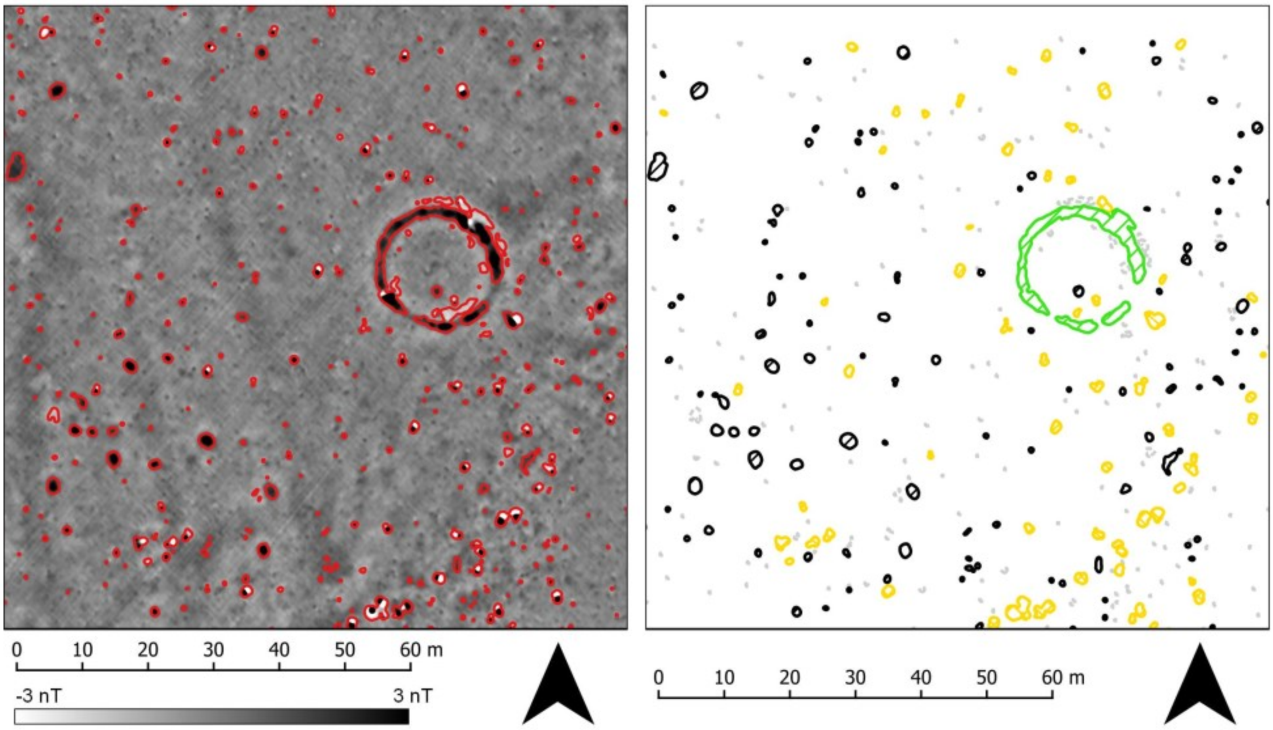


*Fig. 3. From left to right: a) Magnetogram with vectorized anomalies. b) Anomalies semi-automatically classified as dipoles, pits, noise and a ditch feature. (© DAI/L. Goldmann)*

## The next step

The tool developed by the DAI facilitates the vectorization and interpretation of large survey areas considerably. Fields covering several hectares could be analyzed and visualized with an easily readable, classified vector map within minutes instead of hours. Tests so far show that it is very well suited for features like pits or well-defined dipoles while it does not catch linear features like long ditches or walls with the same success. Of course, these tools do not replace the human analyst, who has to set the parameters and make the decisions in the end. However, they provide an effective assistance as well as enabling transparency and reproducibility of the results. Further terrain parameters or other statistics are to be tested and eventually integrated into the workflow, which in principle would also be suitable for other types of survey data, such as electrical resistivity (ER), ground penetrating radar (GPR) or aerial photography. In the future, the plugin will benefit from the use, testing, critique and input of the GIS-Community.

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# LiDAR on trial

## An overview on the national LiDAR support for the archaeological research on Mediterranean unfavourable areas

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***Keywords:*** *LiDAR—multisensory prospection—farming fields—raster visualization—Mediterranean territory*

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### Introduction

The LiDAR (Light Detection and Ranging) prospection is widespread in several European territories, especially in the northern part of the continent, where forests and high vegetation cover a large percentage of territory. The ability to penetrate the canopy and detect the micro-relief of topographical features in inaccessible areas by optical remote sensing tools has led to the proliferation of this technology in such kind of area, but the investigation of its potentialities has reached other kind of territories, not covered by trees (Opitz and Cowley, 2013). As a matter of fact, one of the first ever employment of the LiDAR technologies did occur at Stonehenge, where important results have been achieved, despite the absence of canopies in the landscape. More often in the last decade, the application of LiDAR gradually has shifted southward, toward Mediterranean areas where several projects demonstrate fruitful results for the landscape archaeology.

### Tested territories and research aims

During the last decade, the Italian territory has been recorded through LiDAR on some spots with encouraging results, as García Sánchez (2018, pp. 1–2) explains. These experiences have supported the application of LiDAR to other Italian areas to maximize the archaeological information provided by this remote sensing technology even in critical areas not completely responsive to this technology. The aim of this paper is to draw attention to the use of the ALS (provided by the Italian Ministry of Environment) in territories where aerial photography has already proven an extensive presence of archaeological features and to investigate the chances of usability of public Lidar in extensive research. The first examined area is the Tavoliere, Apulia that in the last forty years is characterized by a quite intensive farming that is going to change its landscape since; the other one is Ostia Antica, where unexcavated areas provide interesting sparks for a systematic application of ALS, but both urbanization and farming represent a threat to the archaeological record.

### The Tavoliere plain

After the Second World War, the Tavoliere plain became a privileged field for the aerial photography analysis (Bradford, 1957), revealing an impressive and unique amount of archaeological anomalies related to a complex palimpsest of settlements running from the Neolithic to the Medieval times. This abundance of archaeological presence has inspired the testing of ALS (Airborne Laser Scanning) technology despite of the high percentage of farming developed in the last forty years that could have damaged part of the archaeological record, especially the micro-reliefs record that is mostly affected by the increasing farming activities.

### Ostia Antica

The Ostia Antica landscape has favoured several topographical and aerial prospections due to its archaeological importance and historical role. This research has displayed a promising field for the evidences that aerial photos are able to detect (Martin et al., 2002, pp. 259–274). Despite these examples, LiDAR prospection has not been planned yet in neither of the numerous projects involving Ostia Antica. The application of ALS on this kind of landscape has revealed several information on archaeological features, but numerous limits can be equally observed.

## Methodology

Italian Ministry supplies LiDAR data (1 × 1 m of resolution) under various file extensions and, where available, the point cloud has been classified and processed. Particular attention was paid to the raster elaboration of the data (Kokalj and Hesse, 2017): it is a crucial point of the entire process of elaboration and resulting interpretation of the data. For this reason, it is interesting to discriminate the appropriate visualization for each case and to speculate on the possible correlation between landscape features and the best raster view.

Moreover, ALS has been systematically compared with aerial photos, satellite images, cartography (both modern and historical) (Fig. 1) in order to validate the detected features. In particular, the stereoscopic analysis of stereo-pair aerial photos allows to better understand the micro-reliefs detected by LiDAR and to evaluate both the efficacy of the LiDAR data and to observe the changes occurred in the landscape in the last decades. The last one is possible when the stereoscopic view is performed on historical aerial photos.

a b c

*Fig. 1. Via del Sabazeo, Ostia Antica: a) historical aerial photo (SARA, 1930 c.); b) GeoEye01, July 6, 2015, RGB (© DigitalGlobe); c) Hillshade LiDAR A45-H10-Ve2.0.*

## Expected results

The selected areas present several critical issues for a successful application of LiDAR. Farming (i.e. Tavoliere plain) as well as urbanization (i.e. Ostia Antica) have probably deprived the micro-relief of numerous remains, but a moderate percentage of evidence has been detected (Fig. 2). The analysis and comparison of these features with other sensors and sources has led to speculate on numerous matters, such as the archaeological record preservation, the specific characteristics of the archaeological features, the landscape management and so forth, figuring out a promising application in these areas, as well as on areas presenting their same issues.

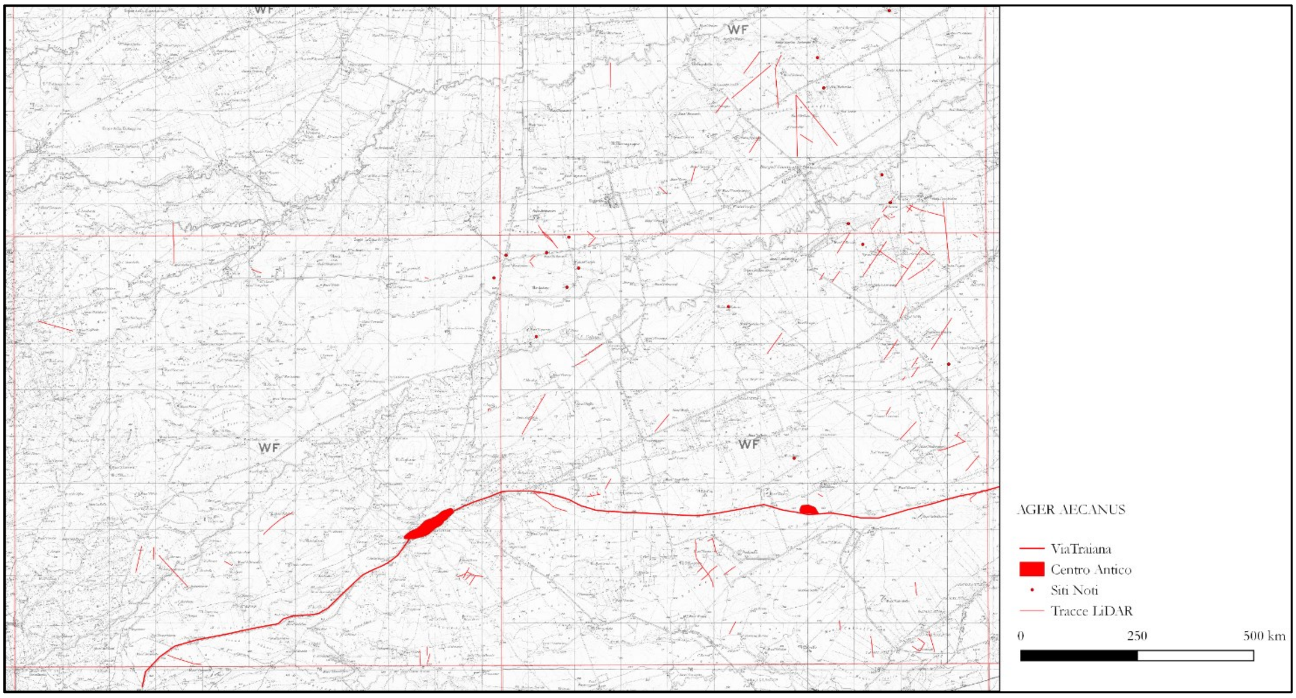


*Fig. 2. Map of the LiDAR features detected on the Tavoliere Plain.*

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## Session:
## Visualising the past

### Defining the standards for digital reconstructions of past landscapes

Cristina MOSCONI | Andi SMART | Fabrizio NEVOLA

# Visualising the past

## Defining the standards for digital reconstructions of past landscapes

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***Keywords****: immersive technologies—past landscape—digital reconstruction—data authenticity—uncertain data*

With the rapid advances in immersive technologies, Virtual Reality (VR) and Augmented Reality (AR) are currently re-emerging as affordable ways providing new potentials for heritage organisations and agencies to access new and attractive ways of informing and involving the public. A constantly growing number of immersive experiences of past landscapes and cityscapes are now available to the general public. These virtual reconstructions aim to offer insights on the original look of lost and/or altered monuments and portions of the urban fabric of ancient cities and landscapes. Indeed, past cityscapes can be digitally recreated as immersive VR experience, and lost urban features can be 3D modelled and then be superimposed to the reality using AR. But, how do we communicate to the public the breadth of research that lays behind the digital reconstruction? How do we present authentic data in an engaging way? Which is the best way to convey to the public the uncertainty or lacking of research data? These are just few of the 'hard questions' scholars and cultural heritage managers are faced with when analysing and developing visualisations of heritage for public engagement.

The goal for this session was to start a conversation about how digital visualisation tools are used to deliver reconstructions of altered or lost past landscapes. We invited participants to submit papers that present either comparative or case-based examples.

Papers were considered:

- Identifying key challenges and lessons learnt in creating landscape reconstructions using uncertain data
- Examining the main issues faced by, and opportunities offered to, cultural heritage practitioners in creating accurate and transparent digital visualisations for the public
- Demonstrating the harnessing of new and emerging strategies to convey data authenticity in digital visualisations

# Visualising the Past through the Virtual Image

## Virtual Reconstitutions as interpretations of knowledge

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**Abstract:** The image has the power to mean something, to tell, to express, to represent, and to present. Based on a reflection upon the place of the virtual image in the visualisation of the past, the present article seeks to answer to the transformations that result from the digital revolution, with implications in our relationship with History and in our experience of the built heritage. With the aim of returning the old Convent of Monchique to the city of Porto (Portugal) and its community, the interpretation of knowledge is explored here by using the virtual image as an instrument for the visualisation of the past, in its visibilities and invisibilities, through interpretative exercises of the past, guided by historical accuracy, authenticity, and scientific transparency. Due to the profound formal and functional changes it has undergone over time—even prior to its foundation, in the 16th century, and up to the present—, the convent presents itself as an ideal example to test the use of scientific methodologies and their validity in an interpretative visualisation of the past.

***Keywords:*** *Virtual image—digital reconstruction—data authenticity—uncertain data—reconstructions*

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## Introduction

The visualisation of the past through the virtual image poses important challenges to our interaction with History, namely by questioning the transformations that the digital universe influences our experience of the built heritage. Starting from the very definition of virtual—here understood, in a broad sense, as the whole of the digital universe—, the virtual image must be perceived in its deep need to "give a representation of itself, to represent its interiority, to represent the visible and invisible worlds, to show these representations, to create, therefore, a universe that duplicates, unfolds, or exists parallel to the digital universe (...) (Goliot-Leté et al., 2011). This whole set of intentionalities is manifested in the relationship of the virtual image with the digital universe, by the desire that it has to dominate it, understand it, approach it, exorcise it, honour it, appreciate it, and enjoy it, or in the search to affirm its specific existence in it (Goliot-Leté et al., 2011). It is also in this sense that it can be said that "digital (or virtual, or artificial) environments are nowadays helping us to understand our physical world" (Rubio-Tamayo and Botelho, 2018).

However, one should not confuse image with medium. The concept of image can only be enriched if we “speak of image and medium as two sides of the same coin, though they split in our gaze and mean different things.” (Belting, 2014).

As we have seen before, great expectations were placed around the image, perceived, in its multiple functions and potentialities, as an instrument at the service of knowledge. By recording built heritage in the present moment, we are also contributing to its preservation and to the creation of memories for the future. As they can present different origins, images are able to fluctuate between a physical and a mental existence (Rubio-Tamayo and Botelho, 2018). Furthermore, a distinction can be made between natural images and those that are man-made (with or without the help of machines). By exploring the semiology of image, we would obtain other categories, such as: single image/multiple images, fixed image/moving image, and man-made image/image produced by a device (Belting, 2014).

On the other hand, and as it is clearly evident, digital technology has allowed to be brought up for debate new questions to the philosophy of the image, which has had an impact on the reformulation of well-known concepts based on the study of painting or photographic image (Rubio-Tamayo and Botelho, 2018). At the same time, the image of the past has accompanied the digital switch-over of important epistemological debates, present in disciplines such as Art History and Archaeology, that are, in turn, heirs of an existing duality between modern and post-modern thinking.

The aim of this article is not to take sides with any of the antagonistic positions defended by either Virtual Archaeology or Cyber-archaeology. We are sensitive to their arguments, and we are aware of the importance of this debate for the clarification of the significance of the image, in the documentation of the Cultural Heritage, especially in what concerns the built heritage.

In conclusion, this article also takes into account the consensus generated by the international scientific community, in particular with regard to the production of international charters and protocols, around computerised visualisation and virtual archaeology that aim at their application in a wide scope, as well as the good practices carried out in similar scientific exercises, applied internationally.

## The Knowledge of the Past and Cultural Heritage in the Digital Age

The Digital Age, characterised by technological development and the practically unlimited dynamization of information flows, is changing the way human knowledge is built. “If the human knowledge is rapidly migrating in digital domains and virtual worlds, what happens to the past?" (Forte, 2014). In light of this new approach, of a Digital Cultural Heritage, it is necessary to adopt a memorial practice that conditions/inform innovation, without nostalgia for the past, and that rejects the various forms of museumization (Suppia, 2008). Given the past was always observed from the present, the knowledge of cities and their built heritage implies, as well, the understanding of our place in contemporaneity (Forte, 2014).

From the concept of Virtual Archaeology to the approach proposed by Cyber-archaeology, a new paradigm is emerging. M. Forte, referring to the latter, highlights the idea of “potential past” as the most appropriate way to classify the process generated by the co-evolution of information deriving from human evolution, and cyberinteraction generated by different worlds, with knowledge being validated by the relationship between the present and the past (Choay, 2015). Based on the assumption that the past is something that cannot come back into existence, it was argued that the images we can obtain from it are only simulations. Thus, from the same past, we will be able to formulate different hypotheses, capable of coexisting with one another, in a digital ecosystem. The systems of digital recording and 3D information align themselves in this assumption, marking a difference in relation to traditional systems.

In the context of what we have been describing and due to the importance that the digital computer has gained, concepts such as "computerised visualisation" have been asserting themselves and gaining popularity. According to the London Charter, this is the "process of representing visual information with the aid of computerised technologies" (Câmara et al., 2018). "The setting up of the digital format and computers as means of visual representation requires an awareness of the image as a virtual object, that is to say, the image as a set of data that can be manipulated mathematically (Barceló et al., 2000). Since a digital or virtual image is, in its essence, a set of bits arranged on a surface, the idea of vision must go beyond the mere idea of sight, by including factors such as multisensoriality, memory, imagination, readability, and interpretation. In this context, digital technologies, intersected with the historical practice, allow the convergence of a perspective of the past as a sensorial-perceptive reality (2010). On the other hand, they create conditions for a prophylactic preservation of heritage assets by their communities (Denard, 2014), linking them to the future, by creating a memory/record in the present.

The creation of augmented and virtual realities, with different forms of interaction, simultaneously reveals new forms of visibility and visuality, with the screen acquiring an enormous cultural relevance (Matias, 2016). The screen, by definition, is a "flat surface that reflects light and on which images are projected (…) [is] where the image, in the spectator's eyes, is materialised" (Câmara et al., 2018). Nowadays, the screen no longer assumes the place of the mere visual representation, profiling itself as a space where the spectator conducts operations, interprets and chooses what is in front of him, thus, as a consequence of technological development, being able to immerse himself in the image. It lies in the power of the spectator the possibility of translating, in his own way, what he understands, making him able to connect the screen—in a scientific-interpretative way—to his singular intellectual path.

The distinction between visible and invisible also leads us to the interpretation of images. It is important to distinguish visibility and invisibility in what it was presented to us, whether we are talking about the real world or the virtual worlds. The interpretation of an image goes through its meaning and through its "reading" by its viewer. "We all know, from direct experience, that images are not visible in a unique way, entirely determined by the perceptual apparatus, and that we only see in them, in the full sense of the term, what we are capable of understanding" (Aumont, 2011). Summoning the concepts of sign and signification,[1] the issue of interpretation is a general semiotic and philosophical matter that goes beyond the image itself. In the years 1960–70, semiolinguistics has introduced the notion of code, which, perceived in its different nuances—from the individual to the universal—, brings an unequal domain to subjects, through its context (Aumont, 2011). While perception could be compared to a process of "decoding", concrete representation can be seen as a process of "code posturing" (Massironi, 2015).

[1] See (Eco, 1984).

In a postmodern context, increasingly dominated by algorithms and by the proliferation of subjective criteria, interpretation now plays a decisive role for the social sciences and the humanities, assuming itself as a keyword in this process of knowledge. Aware of its importance, and its application to the History of Architecture and to Digital Humanities, it is necessary to attribute new meanings to the unknown, and interpreting was also a way of learning how to manage the lack of knowledge. In the case of derelict and transformed buildings, as is the case of the example that will be addressed below, this issue is particularly relevant.

Jacques Rancière, in his attempt to overcome the idea of image, either as a double of something or as a medium at the service of the performance of an art, comes forward with the idea of thoughtful image (Aumont, 2011). As it is well known, an image will not hypothetically, be a thinking object, but rather an instrument of thought. “Thus, a thoughtful image is an image that contains unthinking thought. A thought that is not likely to be attributed to the intention of the one who produces the image and causes an effect on the one who sees it, without the latter linking it to a particular object” (Aumont, 2011; Matias, 2016). In other words, a virtual image of the past—reflecting a rigorous methodology of scientific research—may contain levels of knowledge that go beyond the very intention of the one who produced it. Here, once again, we bridge the gap to Cyber-archaeology and to the concepts that serve it, such as autopoiesis, enactivity, and affordances, among others.

In conclusion, the virtual image of the past should allow its evaluation by other researchers, by making it easier to verify its authenticity and historical accuracy. On the other hand, we must ask ourselves how can these images also be thinking images? That is, how can their interpretation—also conditioned by factors such as historical and visual culture—bring new knowledge beyond what was being intentionally transmitted by its author? These questions are of the utmost importance and reinforce the need for scientific rigour in the processes of creating virtual images, particularly with regard to international protocols and procedural consensus resulting from the broad debates in this sector. Only in this way can the possibility of a truly transparent and interdisciplinary shared construction of knowledge be guaranteed.

## Digital Reconstitution Processes

As mentioned here before, the new technologies associated with the sector of Cultural Heritage bring a renewed debate to this discipline. By valuing visuality and by seeking to offer experiences that recreate the past that are increasingly realistic, we also get closer the concept of time travel, with an attempt to show historical environments, inhabited by virtual characters (Câmara et al., 2018).

With the emergence of the avatars of the historical monument (Carpetudo and Lopes, 2017), one questions how to put the technologies at the service of the visualisation of cultural content and contribute to the visualisation and interpretation of the past. This question also extends itself to the elaboration of propositions of virtual reconstruction and recreation (or simulation, as Cyber-archaeology points out) of the built heritage. We recall here, once again, the rupture established by Cyber-archaeology in the epistemological debate. We retain the words of M. Forte, when he suggests that the past could not be reconstructed but simulated (Aumont, 2011). While it is true that this denies the exact (or even approximate) nature of a virtual reconstruction or recreation, for example, the importance of the context in the characterisation of a reality was reinforced. Once again, and as opposed to this, Virtual Archaeology defends the scientific and objective aspect of its methodology; on the other hand, Cyber-archaeology, flatly refuses the existence of a single reality, but rather its multiplication according to the existing points of view.

In addition, it is necessary to be aware of other parallel phenomena. It is therefore essential to bear in mind that the boundaries between reality and simulacrum tend to fade out, which may lead to substitution phenomena in a new way for us to apprehend and relate ourselves to the world.

Moving away from the debate polarised by modern and postmodern thinking, we will now focus our attention on the process of image production. In this sense, it is important to keep in mind that, through their technical reproducibility—along with the debate concerning fundamental issues, such as authenticity and aura, mentioned by Walter Benjamin (Rancière, 2017)[2] –, the processes of image production live in a situation of constant questioning. As it has been seen, throughout history, the discourses on the image and the ways of producing and thinking about it have changed (Hamurco and Hamurcu, 2018). However, “creating an image of an object means extracting all its dimensions, successively: weight, depth, smell, space, time, continuity, and, obviously, meaning” (Choay, 2015). Thus, its results will not be only visual, because they result from a multimodal and multisensorial interaction (2010), and are syntheses of complex research processes, on themes such as spatial experience or its relationship with its surroundings.

Digital reconstruction processes were presented as a viable, non-intrusive, versatile, and completely reversible solution in the way we know the built heritage, in its diachrony and synchronicity, allowing the discussion of different hypotheses. They are also a key element in the dissemination of the built heritage, by seeking to dilute the barrier between scientific research and its interpretation and presentation to the civil society. On the other hand, it is also possible to elaborate three-dimensional models that evolve in parallel to the research phase, and even surpass it. They must be characterised by their transparency, not only from the perspective of the validation of the scientific methodologies used, but also as a dynamic process that brings the theoretical neutrality of information to the higher level of knowledge (Solà-Morales, 2016). As it will be seen later, all these topics have been discussed and theorised in protocols with international and transversal application to Cultural Heritage. Following the plea of the London Charter (2006, 2009, and 2012), criteria have been defined for its application to specific sectors, such as digital archaeology (Seville Principles, 2011–12).

If, in a certain sense, the level of reality could be measured by the degree of iconicity or abstraction of a representation, it is important to undo the misconception that, as Massironi said, its purpose is confined to a credible reproduction of reality (Benjamin, 2018 [1935]). As it was initially seen, the concept of the thinking image is also present here, in which the image is not limited to its capacity to resemble reality. Thus, and notwithstanding what has been mentioned here, the image is subject to countless processes aimed at transforming it into an object of communication of a precise intentionality. That could be observed, for example, in the digital manipulation of the photographic image, with the attenuation of its properties, including the correction of lights and colours, and the creation of homogeneity and visual continuities, in a set of post-production processes (Marques, 2006). This

[2]John Berger told us about the reproduction, applied to painting. According to him, "(...) reproduction allows, or even makes inevitable, that the image may be used for multiple purposes, and that the image reproduced, unlike the original work, can lend itself to all of them" (2018).

allows, for example, to eliminate the effects of weather conditions and variations in lighting, but, paradoxically, it eliminates the presence of the real context, in the transformed image. In an objective way, the verisimilitude of the image, in relation to its author's intentionality, may not coincide with the perceived reality itself. This means that the virtual image of the past should not necessarily seek photorealism, but it may have an interest in studying other elements, such as volumetrics, altimetry, differentiation of phases of construction, or the identification of stratigraphies, among others.

Before moving into our case study, a final note regarding the documentary properties of the image: we know of its demonstrative capacity and its power of persuasion, which can inform us of the reality, in a close way, but, on the other hand we are aware of the limitations concerning its descriptive or explanatory capabilities; deprived of linguistic categories, the image itself cannot describe or explain (Worth, 1975). "The image is a fascinating document, as it is immediate, but it never, by itself, an explanation: it needs "instructions for use" (Medeiros, 2007). As we will have the opportunity to show, in the methodology we adopted, the images that we produced will be an illustration of what we have just mentioned.

## Object of Study and Methodology

The issue aforementioned here has been tested in the built complex known as the Convent of Monchique (Porto, Portugal). Some preliminary results have already been presented in international scientific meetings, namely regarding the documentation of the patrimonial assets and the identification of the different chronologies of its construction.

This convent is acknowledged for its cultural importance in the architectural, historical, and artistic fields, reflecting values of memory, antiquity, and authenticity. Due to the profound formal and functional changes it has undergone over time, even prior to its foundation, in the 16th century, and up to the present, the convent presents itself as an ideal example for our reflective exercise around the interpretative visualisation of the past. Selected for its nature, scale, and urban significance, the study of the Convent of Monchique also allows us to question the way in which digital methodologies and tools enable us to better understand a lost or transformed urban environment, while, at the same time, it diffuses its knowledge. This study reveals a great potential for testing the new digital tools at the most diverse levels, both by the methodology and the results that can be achieved. By extension, it also allows us to ask how these strategies are used to re-inscribe the absent/transformed historical city in its multiple layers, within the contemporary environment, and about the connection of civil society with its (in)visible heritage. Due to its peripheral character and its derelict condition, the convent is simultaneously a pretext for the creation of new cultural offerings and a consequent increase in its attractiveness.

This process is attentive, as we have seen, to the epistemological debate between Virtual Archaeology and Cyber-archaeology, and it is based on the principles defined in international charters and doctrines, namely, the "London Charter" (2006, 2009 and 2012), the "Seville Principles" (2011–12), the "Berlin Charter" (2015), the "ICOMOS Charter for the Interpretation and Presentation of Cultural Heritage Sites" (2008), and the "ICOMOS Charter on Cultural Tourism" (1999), answering to the need to ensure the methodological rigour of computer-based visualisation of cultural heritage. At the same time, other models that have already been implemented, that attest to the value and validity of these methodologies in interdisciplinary processes of study and digital reconstitution of built heritage, such as the work developed around the “Lx Convents”[3] project and the SANTACRUZ project[4], are taken into account.

Through an intensive historical and bibliographical research, and a systematisation and analysis of the existing archival, cartographic, and iconographic documentary material (as recommended in the “London Charter” and in the “Seville Principles”), it is possible to obtain the identification, the reconnaissance, and the documentation of the stratigraphic layers of the building and of urban spaces. The Seville Charter recalls, for example, that archaeology is not an indisputable science, and that its hypotheses must be capable of being interpreted according to a scale of veracity, giving the possibility of distinguishing remains preserved at the site from anastylosis and reconstructions. During our visit to the site, a photographic survey was also carried out, making it possible to assess the state of conservation of the building and its current characteristics, such as functions, stocks, alterations, and demolitions. Other indirect methods, such as photogrammetry, have already been tested on elements of the convent, scattered throughout the city, as is the specific case of the Manueline portico that is in the Soares dos Reis National Museum’s possession, and whose result has already been presented at an international conference in the USA (iLRN 2018, Missoula).[5]

Moving forward with a comprehensive historical and artistic reading of the spaces and their successive occupations (see the Seville Charter, namely Principle 5.2: “All historical phases recorded during archaeological research are extremely valuable "), we proceeded with an exhaustive contextualisation (historical, cultural, economic, and social, among others), based on the cartography, the engraving, the photography, and on the written sources, following the guidelines of the Charters and International Conventions that have been previously mentioned. This way, we intend to read not only the existing physical remains, but also its crypto-artistic memory. Therefore, it is necessary to go back and reconstitute the places, in their multiple dimensions, contextualising them, by way of example, historical, artistic, and economically. New perspectives make it possible to include other metaphorical or imaginary languages, translated into a new perception of the built heritage and of the landscape heritage itself, in a reading that includes the territory and the communities. “In architecture, far beyond what the designer-architect may suspect, the thought, the taste, and the pretensions of an era are drawn and witnessed. That is why the architecture lesson is extraordinarily rich and multifaceted, but also very cryptic” (Almeida, 2001).

Covering a very broad chronology of construction, the area corresponding to the old conventual fence contains documentary evidence of occupation since at least the 14th century, when there was a Jewry there, with its synagogue and its private cemetery. Later, from the 15th century, this site was occupied by a manor house (a noble palace). Although we do not know exactly what elements have been taken of the pre-existing buildings, it is proven that the construction of the convent made use

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[3] This project was conducted by Raquel Silva and hosted by the Institute of Art History of the Faculty of Social and Human Sciences (UNL – Universidade Nova de Lisboa). LX Convents Homepage, http://lxconventos.cm-lisboa.pt/ (Accessed: 30 September 2019).

[4] Project started in 2018 and scheduled for completion in 2021. SANTACRUZ Homepage, https://santacruz.ces.uc.pt/en/home/ (Accessed: 30 September 2019).

[5] Tiago Cruz. 2018. Digital Heritage: Digital Drawing and new Research Tools for Investigation in History of Architecture. Hypothesis of virtual reconstruction of the Convent of Monchique (Porto, Portugal). In “Proceedings from the Fourth Immersive Learning Research Network Conference (iLRN 2018 MONTANA)”.

of the structure of the palace, also previously used as the residence of its founders: Pedro Coutinho and *Dona* Beatriz de Vilhena.

From this perspective, studying the Convent of Monchique, with the aim of creating virtual images of its past, is also an exercise that presupposes and includes the study of the occupations prior to its foundation: the Jewry, with its synagogue, and the noble palace.

*Fig. 1. Convent of Monchique in 1865 (© Municipal Historical Archive, Porto).*

## THE VIRTUAL IMAGES OF THE CONVENT OF MONCHIQUE

The former Convent of Monchique is now a set of complex volumetry with an area of 11,065 sq. m and a perimeter of 644 metres. Its urban river front is approximately 235 meters.

The site presents a great topographic variation, with implantation quotas between +5.00 meters and +33.72 meters. The altitude variation of its volumes goes from 5.36 meters (annexe belonging to the municipality of Porto – CMP) to 22.47 meters (east turret). For these reasons, as well as for reasons of functional diversity and conservation, we have opted to proceed to its study after dividing it into different lots. With this, we intend, above all, to make the proposed work feasible in a timely manner (according to point 6 of the “Seville Principles”: efficiency). It should also be noted that this work is in progress and is expected to be completed in 2021.

The division of the area of study into lots and sectors takes into account the property division when the religious orders were abolished in Portugal, in1834, and the consequent sale by public auction. In this sense, the division was made from the property register, a factor that has had profound implications on the function and on the identification of volumetric or typological units. Finally, it should be noted that this procedure makes the research more operational and allows for a more significant number of elements to be studied, which would not otherwise be possible.

Next, we will show, with a section of the old Convent of Monchique, the methodology of using the virtual image as a tool for the interpretation and visualisation of the past. In the methods used, we cannot forget that any “codification” requires a choice (Forte and Pescarin, 2012).

“Any graphic representation is always an interpretation, no matter how faithful to reality it is in proportion and attention to detail. Thus, graphics are always attempts to explain reality” (Massironi, 2001). On the other hand, the balance between emphasis and exclusion is also taken into account, according to which certain principles of the image are highlighted in order to increase its readability, while others are ignored voluntarily and practically omitted (Goliot-Leté et al., 2011).

**Lot 1, Sector A**

As we have seen, in order to facilitate the application of the predefined methodology, the extinct convent was divided into four different lots. With regard to lot 1, it was also necessary to divide it into 4 sectors, defined by their volumetry and functionality. Here, we will follow the study process related to Sector A, which fulfils, therefore, the exploratory functions of this article.

This area, peripheral to the conventual ensemble, was bounded by the walls of the fence, having housed a small Manueline chapel—the chapel of “Nosso Senhor dos Passos” (16$^{th}$ century). Later, the chapel was demolished, and the headquarters of the Clemente Menéres Company was built in its place. This construction was also carried out in a phased manner, throughout the 20$^{th}$ century (according to work permits consulted in the Porto Municipal Historical Archive – AHMP). Currently, it still houses the headquarters of this company, as well as an art gallery, and a car repair shop.

For information concerning the previous occupation/configuration of this place, we consulted the historical cartography, as well as old engravings and photographs, together with the photographic survey of the present situation, carried out by us. Since the new technologies complement, rather than replace the traditional methodologies (as recommended in the Seville Charter, Principle 3: “Complementarity”), the observation drawings of the building were made on site.

For the survey drawing of the current building, we have based ourselves on the survey provided by the architect José Paulo dos Santos, along with the academic studies carried out by Pedro Ferreira (2018) and Ana Vendeiro (2014), as well as on the archaeological survey reports.

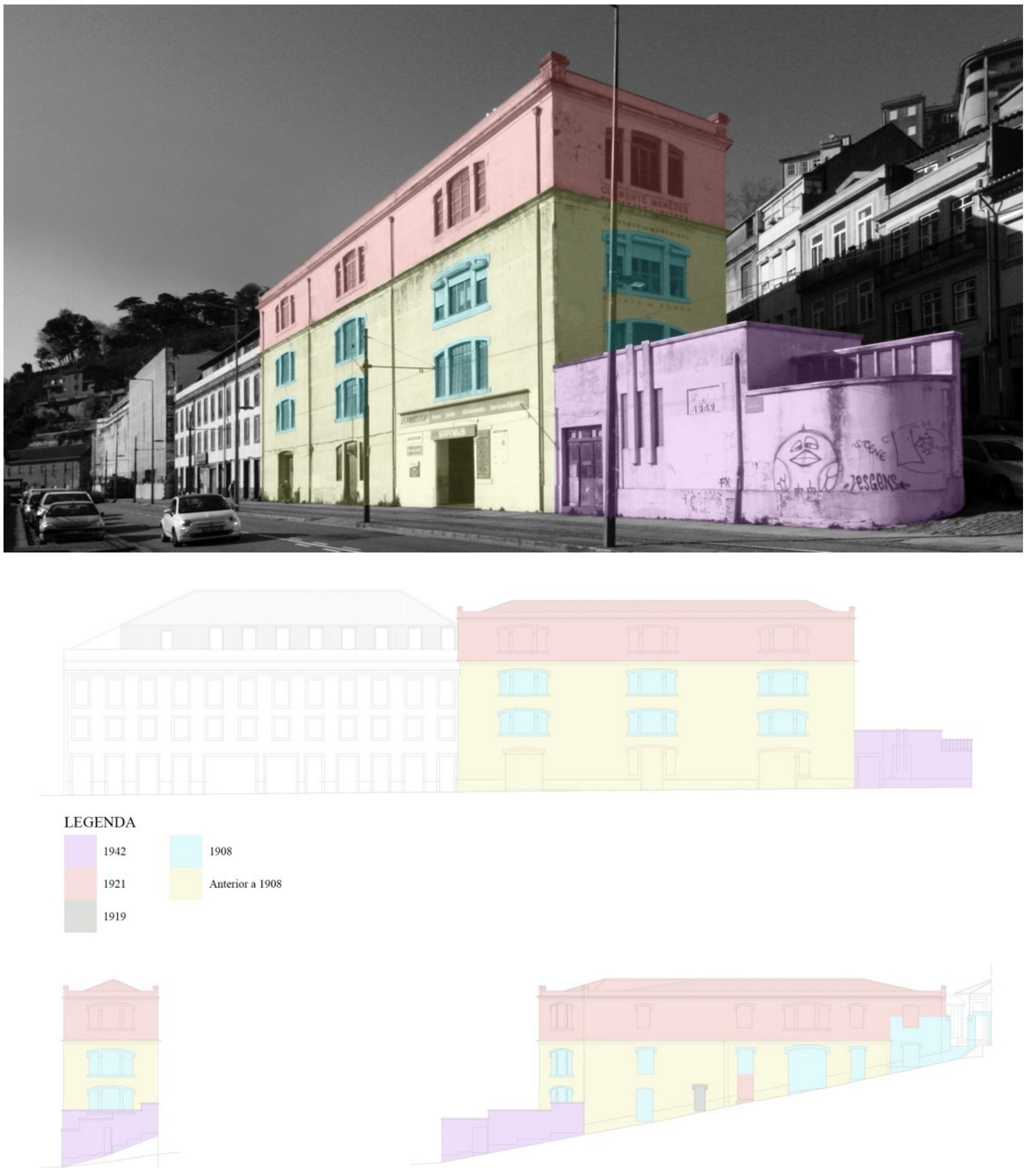


*Fig. 2. Stratigraphic reading of one of the sectors of the convent (© Tiago Cruz).*

## Final Considerations

As it has been pointed out several times, throughout this article, we are facing a paradigm shift. Technology marks and conditions our perception and our vision of the world. In this sense, and in the confrontation of positions that are often irreconcilable with each other, the historical city can be analysed through different digital perspectives (Hamurco and Hamurcu, 2018). In the context of the establishment of digital ecosystems, the current place of the virtual image of the past was questioned. As we have observed, opposing theories propose both their affirmation, as a form of reconstruction/recreation of the past (Virtual Archaeology), and the assumption of the image at the service of a simulation of it (Cyber-archaeology).

What we intend here is to highlight the unequivocal importance of the use—in the different processes involved in the creation of virtual images of the past—of scientific methodologies and their validity as an objective way of addressing the unknown, bringing us closer to knowledge. We know that, regardless of eventually knowing its exact configuration, the Convent of Monchique existed, and that, according to the Principles of interdisciplinarity; purpose; complementarity; authenticity; historical rigor; efficiency; scientific transparency; training; and assessment (Seville Principles, 2011–12), the pondered construction of knowledge may lead us to an approximate virtual image (more or less realistic, and not necessarily photorealistic) of its past. Sharing a positivist view of learning, this exercise of knowledge should also be available to a wider community, through processes of dissemination, acknowledged for the importance of their work, by diluting the barriers between researchers and civil society.

Finally, a few words for the promotion and dissemination of knowledge and of the virtual image of the past: "we are often used to think of "communication" as the final part of the own archaeological process, related to content dissemination. On the contrary, we believe that scientific knowledge and communication should be integrated in one process" (Choay, 2015). Although we consider that this factor may, at the end, open doors to subjective elements, we welcome the questioning surrounding communication as a final part of the archaeological process.

As we do here, communication can be made at different stages of the process, contributing to its assessment (Principle 8, Seville Principles).

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# The Medieval Jewish Quarter in Cologne

## A virtual reconstruction of 6000 m² of archaeology

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**Abstract:** The reconstruction of the medieval Jewish quarter—situated in the immediate vicinity of the Cologne town hall—is a shining example of a scholarly reconstruction. Working closely together, the team of the Archaeological Zone – City of Cologne, the research team of the MiQua project, the TU Darmstadt and external architectural historians/building researchers are currently investigating the architectural history of the synagogue and the Jewish quarter and developing exhibits for a planned museum. The Cologne example of a large archaeological site shed light on the potential of combining features, finds and virtual reconstructions. The most recent excavation results of the Archaeological Zone, City of Cologne as well as earlier records of excavations and features provided the basis for an initial digital model that presents a three-dimensional record of the features within the museum area. Although a plausible layout of the site and the floor plans had been developed, the question what the buildings actually looked like remained unanswered. An engraving of a panorama of Cologne in 1531 by Anton Woensam shows numerous half-timbered buildings. It is thus reasonable to assume that 200 years earlier—in 1349—most buildings in Cologne and in the Jewish quarter were half-timbered. Since Cologne no longer has any extant buildings of the period, the team took suitable examples from Limburg, a mere 120 km away, which still has comparable half-timbered houses of the time around 1300 documented by an extant comprehensive body of scholarly research including drawings of their original structures. These buildings served as models for the reconstruction of the rising walls. In a paradigmatic solution the reconstruction shows on the one hand bird's-eye perspective views which follow a comic-strip-inspired graphic style that underlines the reconstructive and hypothetical nature of the image. On the other hand, the films feature atmospheric tracking shots from a pedestrian's perspective.

***Keywords:*** *digital feature model—virtual reconstruction—graphic representation—Jewish quarter—synagogue*

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## Introduction

The virtual reconstruction of large archaeological sites has a long tradition at the Digital Design Unit of the Technical University Darmstadt. Prominent examples are projects relating to the imperial tombs at Xian with a sub-project devoted to the Terracotta Army (2005–2007), Ephesus in Turkey (2007–2010) and the excavations at Tell Halaf, Syria (2013–2014). Usually, the results of these reconstructions are presented in exhibitions; sometimes they are undertaken as part of the exhibition preparation. Of particular interest in the presentation of virtual reconstructions is the consideration of archaeological features and findings: Not only do digital feature models in film show the starting point of the reconstruction, there is also a trend towards developing exhibits that combine archaeological relics and digital reconstructions in new and exciting ways.

For the MiQua (LVR-Jewish Museum in the Archaeological Quarter in Cologne) in the heart of Cologne—currently under construction—the Digital Design Unit of the TU Darmstadt (Faculty of Architecture) is developing a virtual reconstruction of the medieval Jewish quarter of Cologne and the synagogue. The reconstruction is based on the excavations which cover an area of 6,000 $m^2$. Further to the vestiges of the Jewish quarter, the archaeological exhibition also presents the remains of Roman buildings, among them the foundations of the Roman praetorium.

Several exhibits for MiQua's permanent exhibition are being developed in Darmstadt: an introductory film about the history of the Jewish community of Cologne in the Middle Ages and on what the Jewish quarter may have looked like, another film detailing the four phases of the architectural history of the synagogue, a third dedicated specifically to the Bimah, which sheds light on how the discovered architectural fragments inform the current reconstruction, and, finally, a general introductory film—shown at the beginning of the exhibition—that presents the 6,000 $m^2$ of archaeological exhibition space and introduces the two main subjects, namely the Roman praetorium with the aula regia and the Jewish quarter with its synagogue. The reconstruction of the Roman buildings was carried out at the Technical University of Budapest and was integrated into two films conceptualised and produced in Darmstadt.

The reconstructions thus far are the result of in-depth discussion with all the institutions and individuals involved in the project[1] as well as exhaustive preliminary studies and research that take their starting point in the findings of the Stadtarchäologie Köln (Cologne City Archaeology), which has been conducting excavations on the Cologne Rathausplatz (town hall square) since 2007, and the archaeological findings of Otto Doppelfeld in the 1950s.

## Archaeology and Reconstruction

Drawing on the Cologne example of a large archaeological site, we will shed light not only on the possible combination of features and finds as well as on their digital and haptic images and the virtual reconstructions they give rise to but also on the potential they hold. The paper is typologically structured by scale – from urban space to building to a specific interior.

[1] Of particular note for the Archaeological Zone, City of Cologne are, above all, Katja Klieman (†), Ertan Özcan, Gary White, Michael Wiehen; for MiQua, Thomas Otten, Tanja Potthoff, Sebastian Ristow and Christiane Twiehaus; for the TU Darmstadt, Digital Design Unit: Marc Grellert, Patrik Grlic Shoran Soltani and Norwina Wölfel. As consultants: Pia Heberer, Norbert Nußbaum and Tina Schöbel.

## Urban Space I – Buried Structures

The reconstruction of the medieval Jewish quarter—situated in the immediate vicinity of the Rathausplatz—is a shining example of a scholarly reconstruction. Working closely together, the team of the Archaeological Zone, City of Cologne, the research team of the MiQua project, the TU Darmstadt and external architectural historians/building researchers are currently investigating the architectural history of the synagogue and the Jewish quarter[2] and developing exhibits for the planned museum. The most recent excavation results of the Archaeological Zone, City of Cologne as well as earlier records of excavations and features (Doppelfeld, 1959)—among them a point cloud scan of parts of the features produced by the earthquake monitoring station Bensberg[3] of the Cologne University—provided the basis for an initial digital model that presents a three-dimensional record of the features within the museum area (Fig. 1).

Among these features are the vestiges of the Roman praetorium.[4] The background to the generation of the model was the fact that the architectural firm planning the exhibition did not have access to the site which had been backfilled with sand in preparation of the construction of the museum. The digital feature model was to serve as the starting point for a haptic working model (scale 1:100). Produced with rapid prototyping technologies, it helped the architectural firm to plan the exhibition. It was a stroke of luck for the reconstruction because it provided a good three-dimensional basis.

The creation of the digital feature model—which is not only of great importance as the basis for any reconstruction but also central to the above-mentioned presentations in various media—was based on foundations that were as wide-ranging as they were heterogenous. There were three very distinct areas with different parameters. For the archaeological remains of the praetorium—which have been accessible to the public since 1956 – there was a 3D scan that was combined with current photographs and extant architectural surveys to create a simplified digital polygonal model. The reconstruction of much of the Jewish quarter, on the other hand, relied on the maps drawn up by the Archaeological Zone, City of Cologne team. From a catalogue of hundreds of digital drawings, individual plan drawings and profiles had to be selected to digitally reconstruct sections of the walls in simplified 3D models. Several of the plan drawings lacked vital information about absolute heights, which meant that it was necessary to go back to the digitised original archaeological drawings. A third area lay precisely between the other two. Here the dig and its documentation were still ongoing, so that scans of on-the-spot-drawings documenting the archaeological features were used to create the 3D models.

[2] For an overview of the research results regarding the Jewish quarter, see Kliemann and Potthoff (2019), Kliemann and Wiehen (2019), Potthoff and Wiehen (2018), Kliemann and Ristow (2019)

[3] We are grateful to Prof. Dr. Klaus G. Hinzen for making the data available.

[4] For the most recent research into the Cologne praetorium, see Ristow (2019)

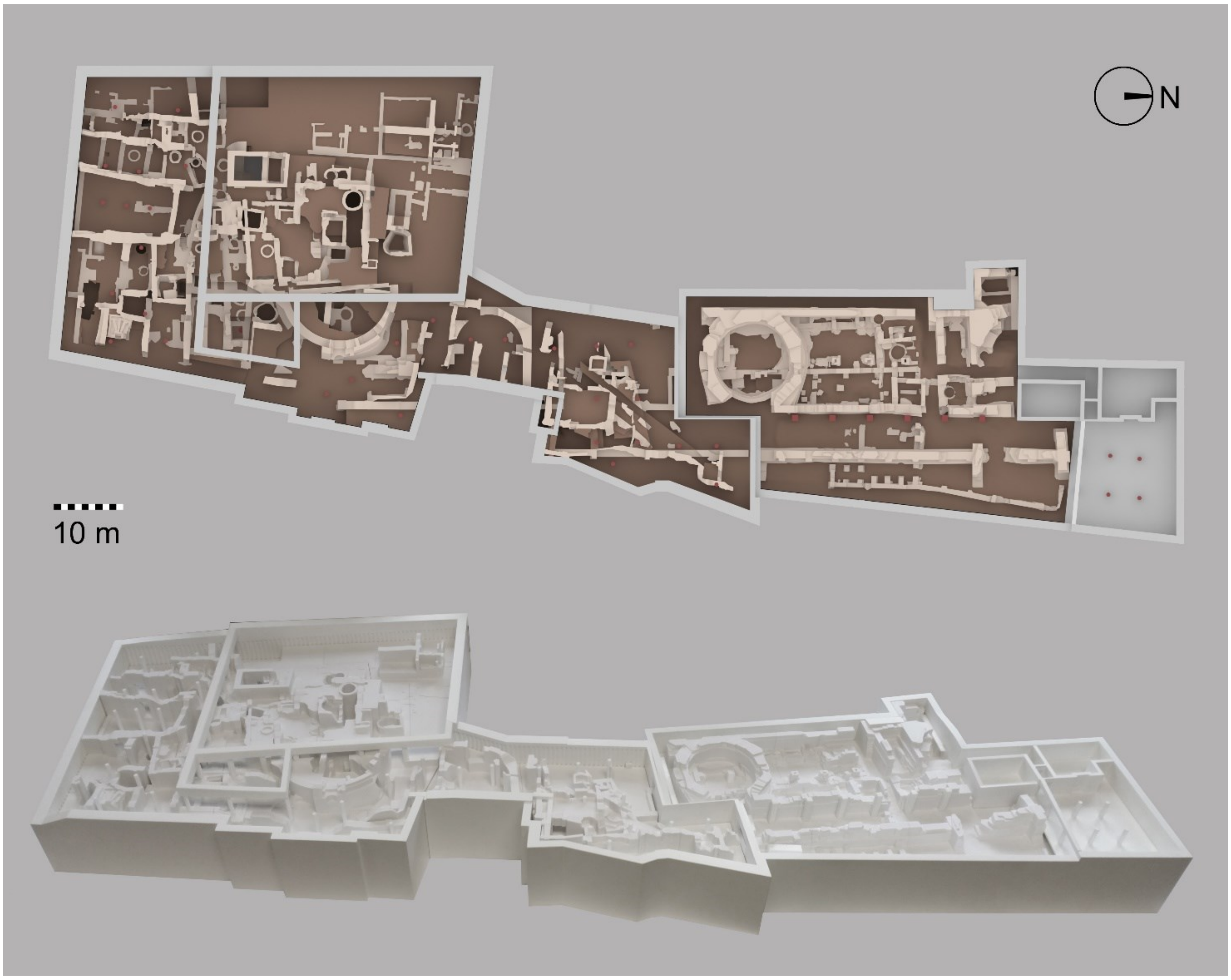


*Fig. 1. Above: digital feature model, below: rapid prototyping model (© Architectura Virtualis, Cooperation partner of TU Darmstadt).*

Proceeding from this digital model, which consists primarily of cellar walls, the next step was to construct a model that included the site and the floor of the ground floor. Because there were only a few spots that yielded information about the medieval street level, further sources had to be consulted to reconstruct the terrain. An architectural survey of the Rathausplatz, which had been part of the Judengasse ('Jews' Lane') in the Middle Ages, showed a ground slope. In a process of parallel translation this was shifted downwards until congruence with the three original heights of the medieval street level was achieved. Research into the architecture of the old city suggests that cellars were lit and ventilated above street level, so that the floor level of the ground floor probably lay between 50 and 100 cm above street level.

As the Jewish quarter was bigger than the excavated plots, the question arose as to whether it was possible to establish the footprints of further buildings. Comparison of the excavated cellar walls with the earliest, relatively precise map of the city of Cologne—the cadastral map of 1837—yielded interesting results. Overlaying the archaeological findings with the cadastral map, which had already been georeferenced during an earlier Cologne University research project under Norbert Nußbaum, showed that the extant cellar walls are almost exactly congruent with the situation of 1837. For an abstract orthogonal representation of the Jewish quarter, further plot boundaries were hypothesised with the aim to delineate a typical medieval architectural structure. At the same time, these results were compared with earlier research into the Jewish quarter. As early as 1920, Adolf Kober, a rabbi and historian, developed a map of the quarter (Kober, 1920). He analysed the Cologne *Schreinsbücher* (Real estate cadastre register) – a unique medieval record of property transactions, recording the sales and changes of ownership of buildings and plots. The *Schreinsbücher* are organised by Cologne parishes, and one of the books is devoted to properties in the Jewish quarter with entries in Latin and Hebrew (Schmandt, 2002, Stern and Hoeniger, 1888). The plan, which was drawn up in Darmstadt on the basis of this multifaceted body of information, shows the possible situation of the period immediately before the pogrom of 23/24 August 1349.[5]

**Urban Space II – Structures Above Ground Level**

Although a plausible layout of the site and the floor plans had been developed, the question what the buildings actually looked like remained unanswered. An engraving of a panorama of Cologne in 1531 by Anton Woensam shows numerous half-timbered buildings. It is thus reasonable to assume that 200 years earlier—in 1349—most buildings in Cologne and in the Jewish quarter were half-timbered. What little had remained of that into the twentieth century disappeared in the destruction of Cologne in the Second World War. The last systematic investigation of the old city of Cologne was undertaken before 1939. Hans Vogt's studies into the appearance of the medieval half-timbered houses suggest that the upper floors were jettied (Vogts, 1966). Since Cologne no longer has any extant buildings of the period, might suitable examples be found in other locations? Limburg, a mere 120 km away, still has comparable half-timbered houses of the time around 1300. What's more, the team could draw on an extant comprehensive body of scholarly research including drawings of their original structures (Ebel, 2002; Bomert, 2002). These buildings served as models for the reconstruction of the rising walls. Based on the drawings, seven of the Limburg buildings have been virtually rebuilt. Where the Cologne cellar floor plans matched, the constructive structures were adopted. The overriding principle was to retain the dimensions of the supporting posts and bays, changing the distance between them by no more than 5 cm. Where that did not fit, it was attempted to insert two supporting posts into the construction in order not to change the system of the construction what inserting only one post normally would do.

The resulting picture of the Jewish quarter with half-timbered houses was complemented by what we know of a synagogue built in stone. The reconstructions—also in stone—of the women's synagogue, the architectural structure above the mikvah, one residential building, an assumed bakehouse and a probable bathhouse were based on historical sources and very scant archaeological evidence.

The question was how to deal conscientiously with the hypothetical nature of the reconstruction of the buildings above ground level on the one hand and the visitors' need for vividness on the other. We believe our approach provides a paradigmatic solution to this problem. A bird's-eye-perspective overview presents the Jewish quarter with the communal facilities of the synagogue, women's synagogue, bakehouse, and *hekdesh* (hospital-cum-poorhouse) in black and white. The emphasis on

[5] The pogroms, which were perpetrated all over Europe and in which Jewish communities served as scapegoats for the ravages wrought by the plague – sometimes months before the disease actually reached the cities – also affected the Jewish population of Cologne. All of Cologne's Jews were either killed or driven out.

the edges of the reconstructed buildings invests the overview with a certain comic-strip aesthetic that underscores the reconstructive character of the representation (Fig. 2, 5). This is complemented by tracking shots from a pedestrian's perspective, in which the reconstruction is atmospheric and features a large number of details based on medieval examples, among them stone socles, stairs, doors, windows, roofing and guttering (Fig. 3, 4, 11).

The two styles of representation – 'comic strip aesthetic' and 'atmospheric' – are embedded in an installation devoted to the history of the Jewish community. The exhibit consists of two elements: a haptic model of the medieval walls extracted from the digital model of the findings and situated within the archaeological exhibition space (the Roman walls and foundations have been deliberately disregarded) and a monitor on the wall behind.

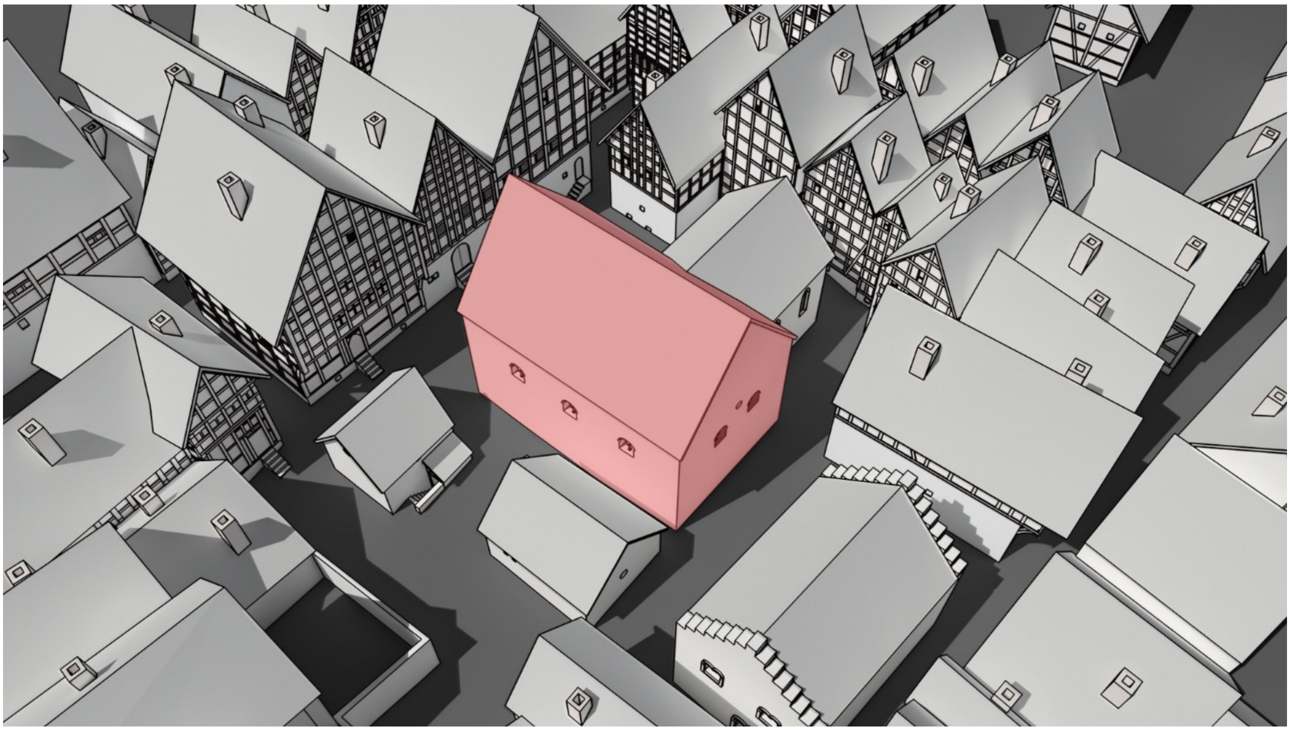

*Fig. 2. Simplified (comic-strip aesthetic) bird's eye view of the Jewish quarter with the synagogue highlighted in red (© Stadt Köln, Dezernat Kunst und Kultur, VII/3 - Archäologische Zone/Jüdisches Museum, LVR-Jüdisches Museum im Archäologischen Quartier [MiQua], Technische Universität Darmstadt, Fachgebiet Digitales Gestalten).*

A beamer can be used to project orthogonal top views of different spatial states onto the model and to pick out specific structures, walls, or buildings. Complementing the projections and synchronous with them, further information is presented on the monitor. For example, as the foundations of the different Jewish institutions are consecutively picked out on the model, the monitor singles out the same buildings in a bird's-eye view of the 3D reconstruction of the quarter. When the monitor plays a sequence of atmospheric tracking shots, the camera movements are echoed by a wandering pictogram that tracks and locates them on the model. This cinematic presentation features several striking moments in which monitor and model home in on one and the same motif (Fig. 6).

The exhibit described above sheds light on how the Jewish quarter with its timbered buildings was reconstructed. It does not provide any details on how and on what basis the synagogue was reconstructed. This is done in a different exhibit.

*Fig. 3. Atmospheric reconstruction of the Enggasse in the Jewish quarter seen from a pedestrian's perspective, (© Stadt Köln, Dezernat Kunst und Kultur, VII/3 - Archäologische Zone/Jüdisches Museum, LVR-Jüdisches Museum im Archäologischen Quartier [MiQua], Technische Universität Darmstadt, Fachgebiet Digitales Gestalten).*

*Fig. 4. Atmospheric reconstruction of a corner in the Jewish quarter seen from a pedestrian's perspective (© Stadt Köln, Dezernat Kunst und Kultur, VII/3 - Archäologische Zone/Jüdisches Museum, LVR-Jüdisches Museum im Archäologischen Quartier [MiQua], Technische Universität Darmstadt, Fachgebiet Digitales Gestalten).*

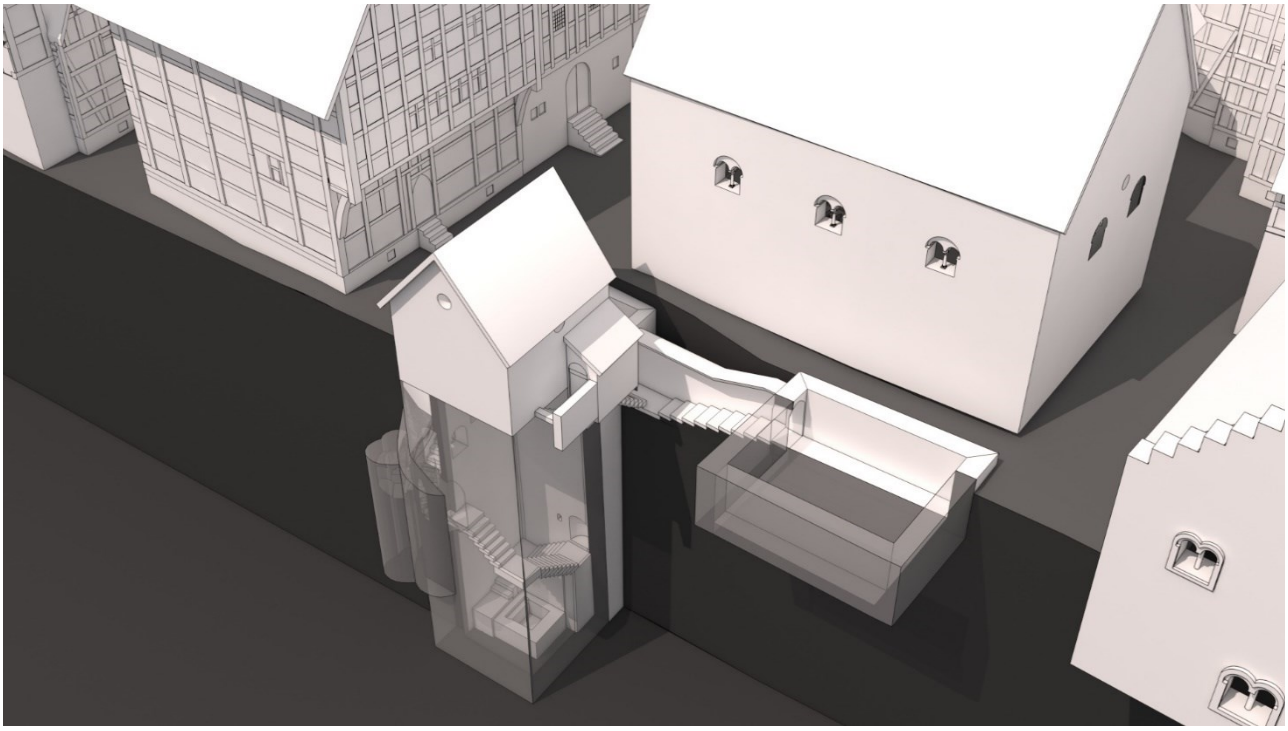

*Fig. 5. Simplified (comic-strip aesthetic) bird's eye view of the Jewish quarter with a cross section of the mikvah (© Stadt Köln, Dezernat Kunst und Kultur, VII/3 - Archäologische Zone/Jüdisches Museum, LVR-Jüdisches Museum im Archäologischen Quartier [MiQua], Technische Universität Darmstadt, Fachgebiet Digitales Gestalten).*

## Buildings

Archaeological features provided not only the starting point for the reconstruction of the urban structure of the Jewish quarter, they also formed the basis of the detailed reconstruction of the Roman buildings and the synagogue. In both cases, the foundations and other architectural vestiges indicate several building phases. The visualisation by means of digital models for the exhibition at MiQua and the academic papers are based directly on these phase-specific vestiges. Fig. 7 shows a still from a film about the Roman praetorium. This paper does not go into the details of that reconstruction—carried out by the Technical University of Budapest under the direction of Zsolt Vasáros—instead it focuses solely on the reconstruction of the synagogue undertaken in Darmstadt.[6] The medieval synagogue was located at the very heart of the city, less than a hundred metres from today's old town hall. Written sources date its construction to either 1012 or 1040. Until the expulsion of the Jews in the Middle Ages in 1424, four distinct construction phases can be distinguished:

Phase I: 1012 / 1040 to 1096

Phase II: $12^{th}$ century to $13^{th}$ century

Phase III: $13^{th}$ century to 1349

Phase IV: 1372 to 1424

[6] The subdivision draws on the work by Otto Doppelfeld and Katja Kliemann. Doppelfeld identified four, Kliemann five phases. She counted the non-Jewish interim use between 1349 and 1395 as a separate phase. The phases presented here are in line with the planned presentation at the MiQua and disregard the non-Jewish interim use. This focus on the synagogue seemed to make more sense in the context of the planned museum and its audience. See Doppelfeld 1959 and Kliemann / Ristow 2019.

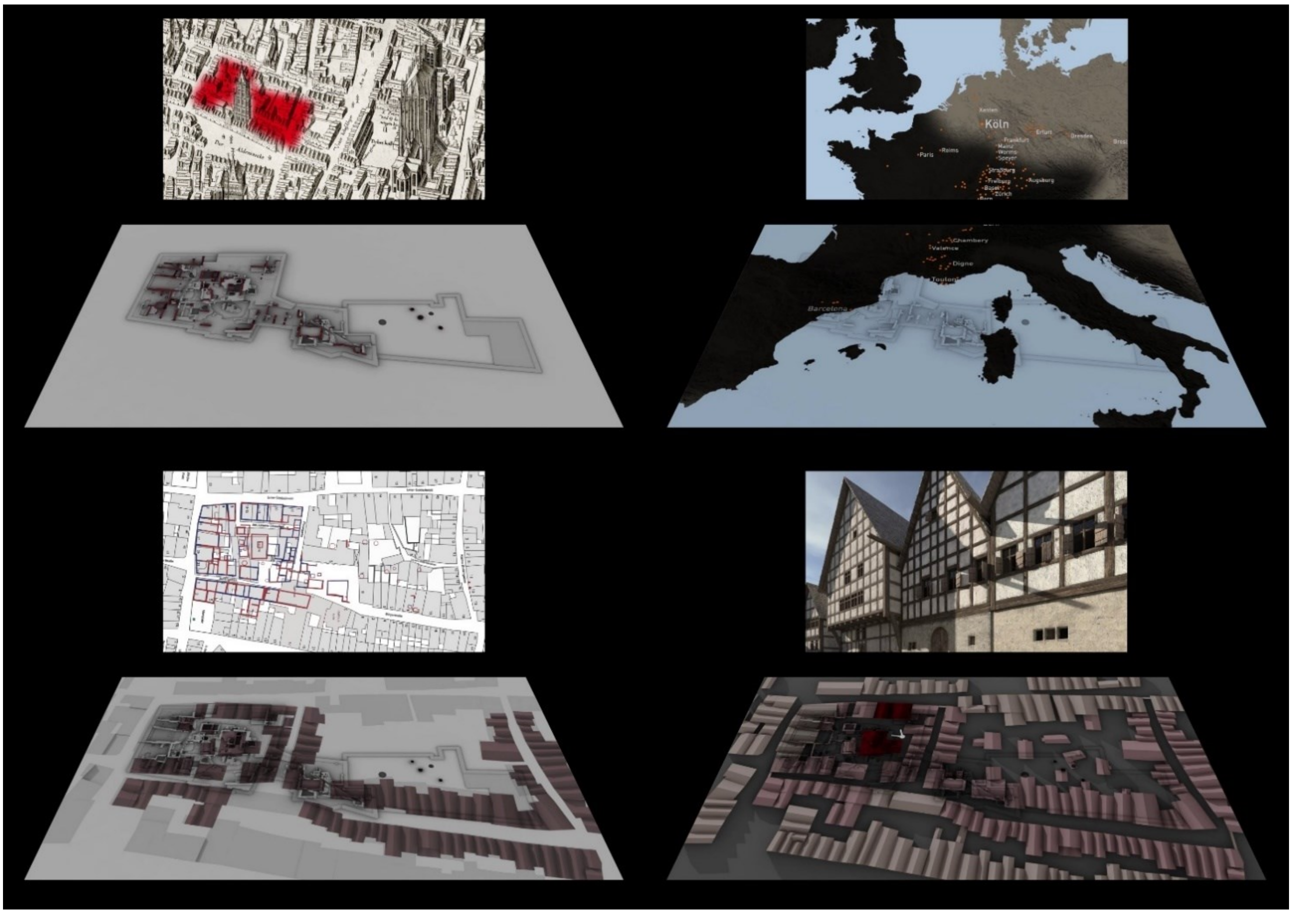

*Fig. 6. Simulation of the installation of the Jewish quarter (© Stadt Köln, Dezernat Kunst und Kultur, VII/3 - Archäologische Zone/Jüdisches Museum, LVR-Jüdisches Museum im Archäologischen Quartier [MiQua], Technische Universität Darmstadt, Fachgebiet Digitales Gestalten).*

Starting point for the reconstruction are the archaeological excavations undertaken by Otto Doppelfeld in the 1950s as well as the more recent excavations by the Archaeological Zone, City of Cologne (since 2007), currently under the aegis of Gary White. During the Second World War, the old city centre of Cologne was largely destroyed. Archaeologists have since been able to investigate the area in front of the old town hall and to excavate the vestiges of the synagogue and the surviving mikvah. These excavations were extensively documented in drawings, photographs, and a detailed diary. The results were published by Doppelfeld. During the subsequent levelling of the site, some original architectural vestiges above the foundations of the synagogue were inadvertently razed. It was not until the excavations of 2007 that attention once again focused on the remains of the synagogue, and numerous fragments were (re)discovered and secured.

The results of Doppelfeld's dig are at the heart of the reconstruction. In Darmstadt, Doppelfeld's documentation was studied, analysed, and translated into a 3D model that outlines the four above-mentioned phases (Fig. 8).[7] In a joint session of representatives of Archaeological Zone, City of Cologne, MiQua and TU Darmstadt as well as associated outside experts, this phase model was

[7] The archaeological results were analysed by Norwina Wölfel at the Digital Design Department. The digital feature model was developed under her aegis with the assistance of Shoran Soltani and Patrik Grlic. The results were discussed, revised, and adapted in Darmstadt in conversations with Sebastian Ristow (MiQua team) and later discussed with the whole project team of Archaeological Zone - City of Cologne, MiQua and TU Darmstadt.

discussed and developed further. The models presented here reflect the state of the investigation as of February 2020 (Fig. 9, 10).


*Fig. 7. Reconstruction of the Roman Aula Phase IV (© Stadt Köln, Dezernat Kunst und Kultur, VII/3 - Archäologische Zone/Jüdisches Museum, LVR-Jüdisches Museum im Archäologischen Quartier [MiQua], Technische Universität Budapest, Fakultät für Architektur, Technische Universität Darmstadt, Fachgebiet Digitales Gestalten).*

**Phase I – 1012/1040 to 1096**

The vestiges feature four ashlars (red in Fig. 9, top left) that are interpreted as part of the structuring of the facade. The absence of infill between the two central ashlars suggests an entrance. The western wall is reconstructed as the entrance façade with blind arches (Fig. 9, lower left). We do not know how many windows the synagogue had. The assumption is that it had ten round-arched windows, three each on the northern and southern sides and two each on the eastern and western sides. On each of the latter a further circular window has been reconstructed. This hypothetical arrangement follows the surviving window plans in the medieval synagogues of Speyer and Worms.

**Phase II – 12$^{th}$ to 13$^{th}$ century**

During Phase II, the western wall was reinforced. One of the thresholds found on the northern wall could possibly be on a level associated with Phase II. It is assumed that the entrance was moved to the northern wall and that the original organisation of the western façade was obliterated by the reinforcement of the wall. Fragments of a mullioned window, found during excavations near the synagogue in the heterogenous rubble that was the result of the medieval pogroms, have been integrated into a hypothetical reconstruction of the synagogue—but they could also have been part of different buildings in the vicinity. In reconstructing architectural details, the team sought to use extant archaeological finds that could plausibly have been part of the lost original building—in many cases we cannot be absolutely certain that a given fragment was part of the synagogue rather than of another building nearby.

The reinforcement of the western wall and the insertion of the mullioned windows may have been undertaken as part of the restoration work carried out to fix the damages the building suffered in the wake of the Crusade of 1096. Also from this period is the first evidence of a stone plinth, located in the centre of the eastern wall, which supported at the Torah shrine.

Also of note is a threshold on the eastern end of the northern wall. It may be interpreted as a link to a first women's room. However, the size and orientation of that space must remain hypothetical and cannot be reconstructed with any certainty (Fig. 9, top and lower right).

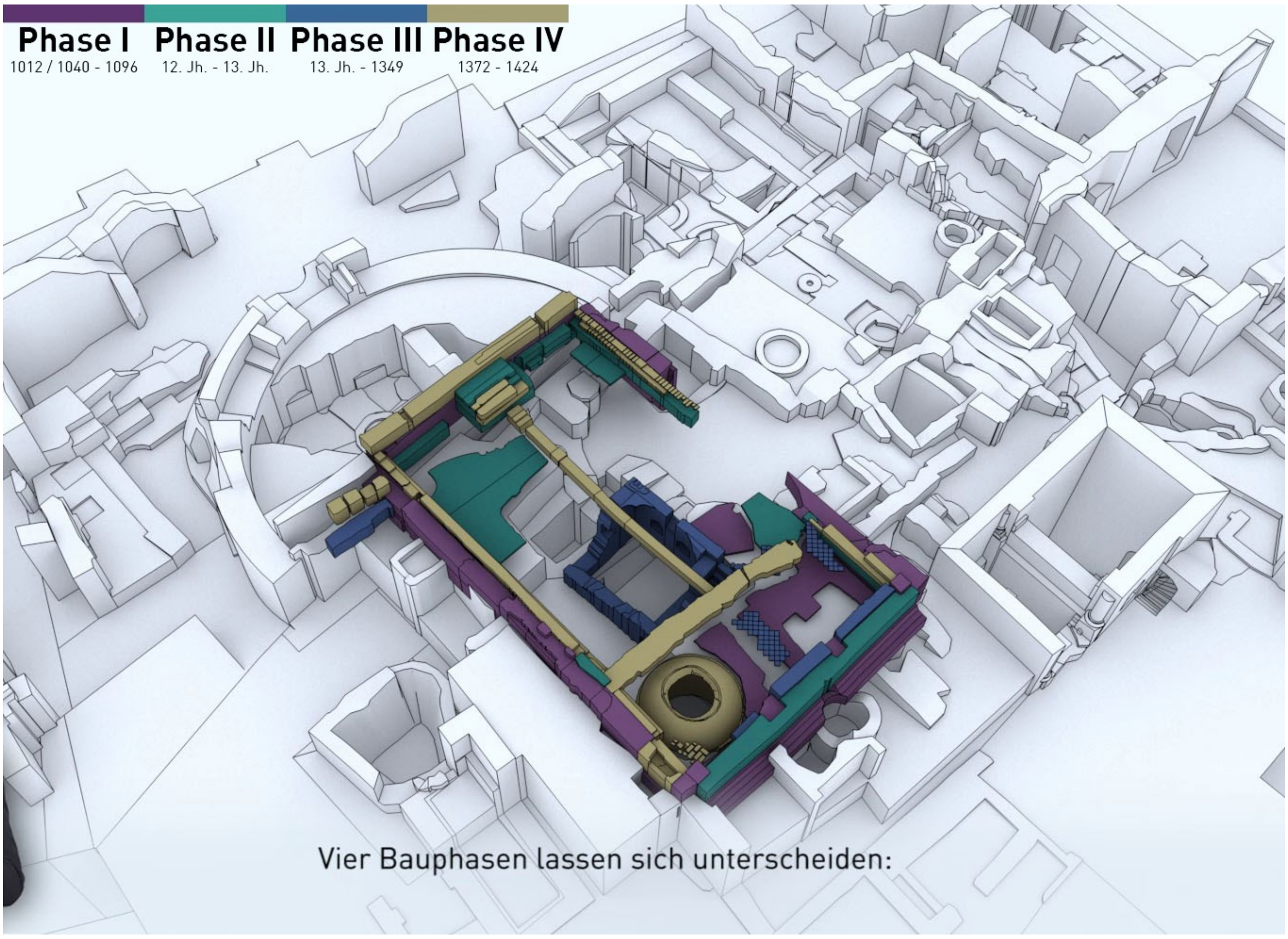


*Fig. 8. Reconstruction of the excavation by Otto Doppelfeld (© Stadt Köln, Dezernat Kunst und Kultur, VII/3 - Archäologische Zone/Jüdisches Museum, LVR-Jüdisches Museum im Archäologischen Quartier [MiQua], Technische Universität Darmstadt, Fachgebiet Digitales Gestalten).*

**Phase III – 13th century to 1349**

There are written sources that testify to the existence of a women's synagogue by 1281 at the latest. Katja Kliemann, member of the Cologne archaeological team, interpreted a section of a wall on the eastern part of the northern wall as the eastern boundary of the women's building. Following Kliemann and in view of the later Phase IV, two vestiges of walls can be interpreted as the boundaries of the later women's synagogue, which was most likely reduced in size after the pogrom of 1349 (Fig. 10 lower right). Kliemann further argued that if these do indeed define the location of the women's building in the later phase, it is not unreasonable to assume that the earlier building had the same orientation. No trace of the western wall of the women's synagogue has been found. In the reconstruction it was placed close to the entrance to create a space of a similar size to the women's synagogues in Worms and Speyer. Fig. 10 lower left and Fig. 11 show the possible appearance of Phase III. Of particular importance in Phase III is the cellar—still extant—which has been interpreted as a storage space and above which a Gothic bimah (Fig. 10 top left) has been reconstructed (more about this later).

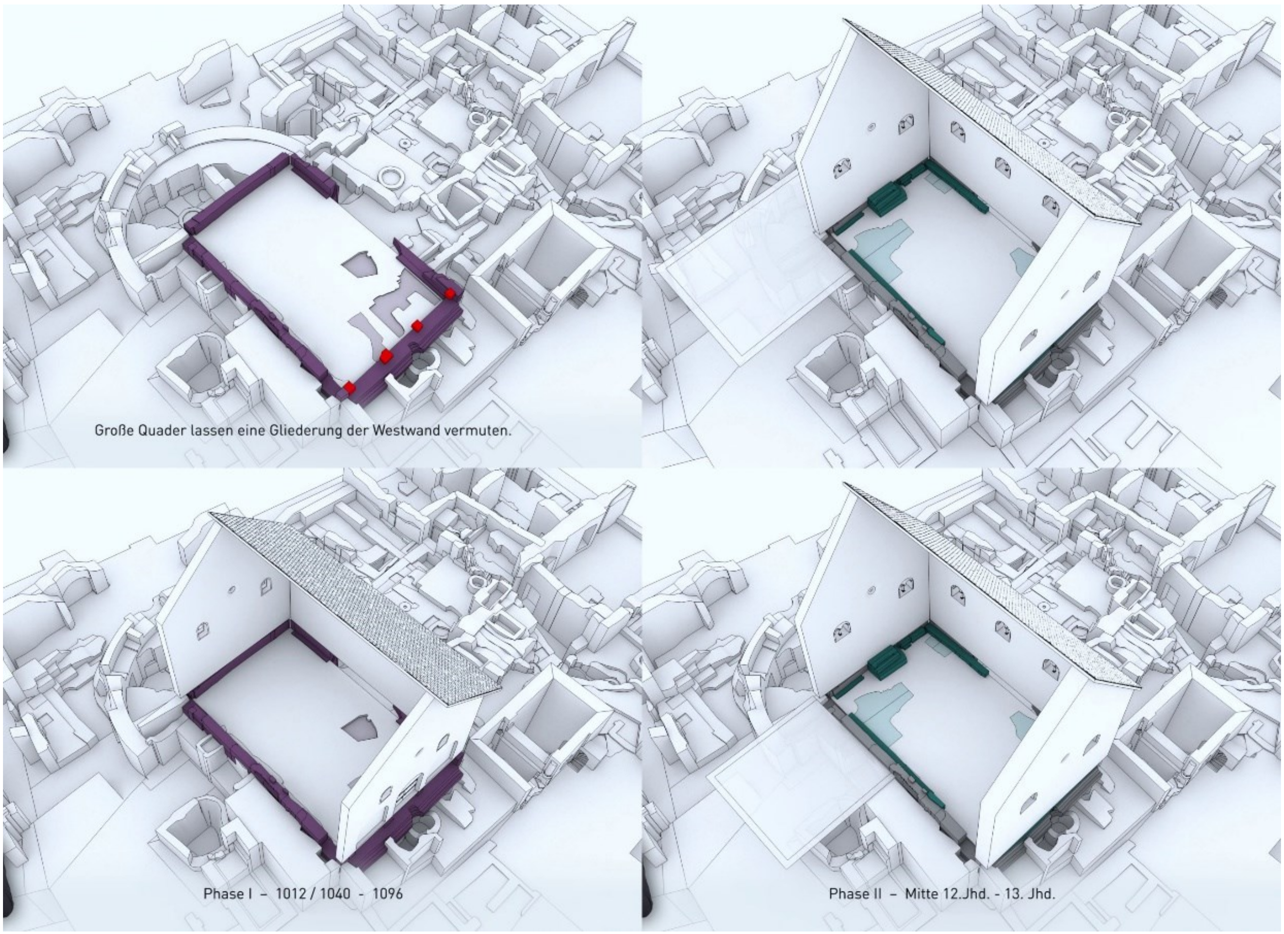


*Fig. 9. Feature model and reconstruction, synagogue Phase I and II (© Stadt Köln, Dezernat Kunst und Kultur, VII/3 - Archäologische Zone/Jüdisches Museum, LVR-Jüdisches Museum im Archäologischen Quartier [MiQua], Technische Universität Darmstadt, Fachgebiet Digitales Gestalten).*

### Phase IV – 1372 to 1424

Annihilated in the pogrom of 1349, the Jewish community re-established itself in Cologne after Jews were readmitted to the city in 1372. Historical sources indicate that in 1395 it became once again possible to use a synagogue on the old site. Between 1349 and 1395, the site had thus been put to a non-religious use by the city's Christian population. The construction of a latrine in the north-west corner of the synagogue terrain is the clearest indication of a profane use. It probably also accounts for the reduction in size of the new synagogue building in the west (Fig. 10 lower right). Another indication of the non-religious interim use of the site is the bit of wall in the middle of the synagogue (Fig. 9 top right), orientated west-east towards the plinth of the Torah shrine. The vestiges of a wall shown in red in Fig. 10 upper right are interpreted as the new western wall. In the west, adjacent to the former western wall of the synagogue, residential use is to be assumed. The two vestiges of walls mentioned earlier, which jut out perpendicularly from the northern wall and are shown in red in Fig. 10 lower right, may have been the exterior walls of the pared-back women's synagogue.

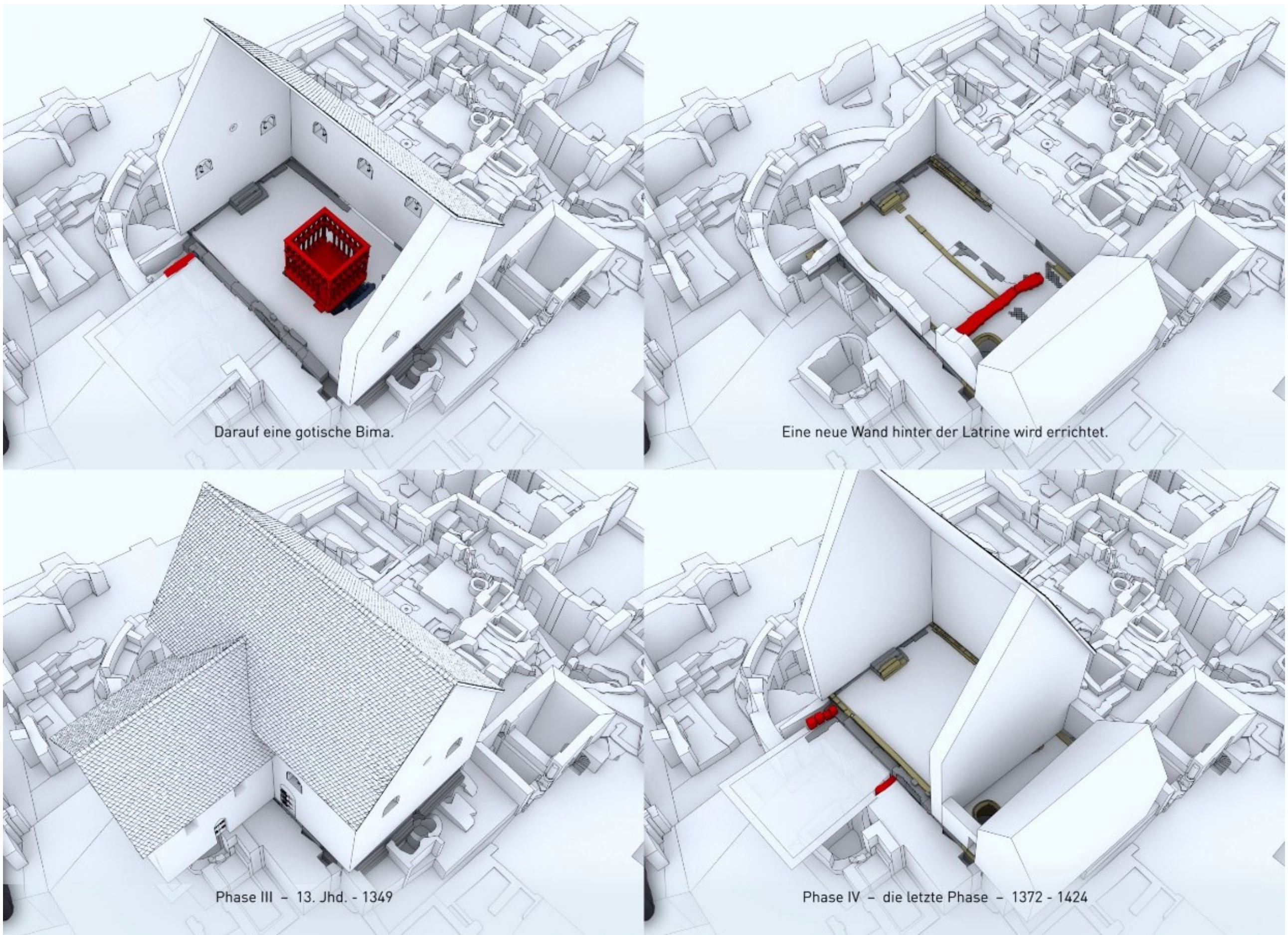


*Fig. 10. Feature model and reconstruction, synagogue Phases III and IV (© Stadt Köln, Dezernat Kunst und Kultur, VII/3 - Archäologische Zone/Jüdisches Museum, LVR-Jüdisches Museum im Archäologischen Quartier [MiQua], Technische Universität Darmstadt, Fachgebiet Digitales Gestalten).*

With the expulsion of the Jews in 1424, the Jewish use of the medieval synagogue came to an end. Two years later, the site was occupied by the Ratskapelle (city council chapel) Saint Mary in Jerusalem. Its dimensions are identical to those of the synagogue in phase I to III. Because the Ratskapelle was destroyed in the Second World War, it cannot be ascertained how much of the architectural fabric of the former synagogue had been incorporated into the chapel.

*Fig. 11. Atmospheric reconstruction of the synagogue, Phase III (© Stadt Köln, Dezernat Kunst und Kultur, VII/3 - Archäologische Zone/Jüdisches Museum, LVR-Jüdisches Museum im Archäologischen Quartier [MiQua], Technische Universität Darmstadt, Fachgebiet Digitales Gestalten).*

## Interior

Even more detailed is the reconstruction of the bimah, which is based on the extant features and findings. In preparation of the archaeological documentation, the MiQua team had already scanned hundreds of finds dug up as part of the excavations ongoing since 2007. Most of the catalogued objects were assigned to the bimah. The virtual 3D models of the finds allowed for an architectural reconstruction of this central element of the medieval synagogue. At the heart of the argumentation are three matching fragments of moulding with traces of two column bases. These three fragments provide a clear indication of the distance between the centre lines, while the still extant cellar beneath the bimah outlined the structure's footprint. This raised the question whether a multiple of the distance between the centre lines coincided with the dimensions of the socle formed by the cellar. The answer was unequivocal: both along the length and the width, multiples of the distance between the centre lines correspond with the dimensions of the socle.

Column fragments and capitals were found to match the cross sections of the column bases of the moulding fragments. They formed the vertical support of the bimah. Gothic construction principles such as the use of compass and ruler set the parameters for the calculation of the Bimah's height. The state presented here is very much a work in progress and not final. As the reconstruction proceeds, it will integrate further finds.

The presentation of the finds in the permanent display of MiQua is to combine originals and virtual reconstructions and draw on an earlier installation. In the exhibition *Restless Times. Archaeology in Germany*, shown from 21 September 2018 to 6 January 2019 at the Martin Gropius Bau in Berlin, several architectural fragments of the bimah were set on a pedestal. A monitor installed above allowed visitors to follow the reconstruction of the bimah and where in the reconstructed architecture the fragments on display could be found. While the film presented the reconstruction step by step, picking out, enlarging, and rotating the individual fragments, a beamer highlighted the corresponding objects on the pedestal (Fig. 12).

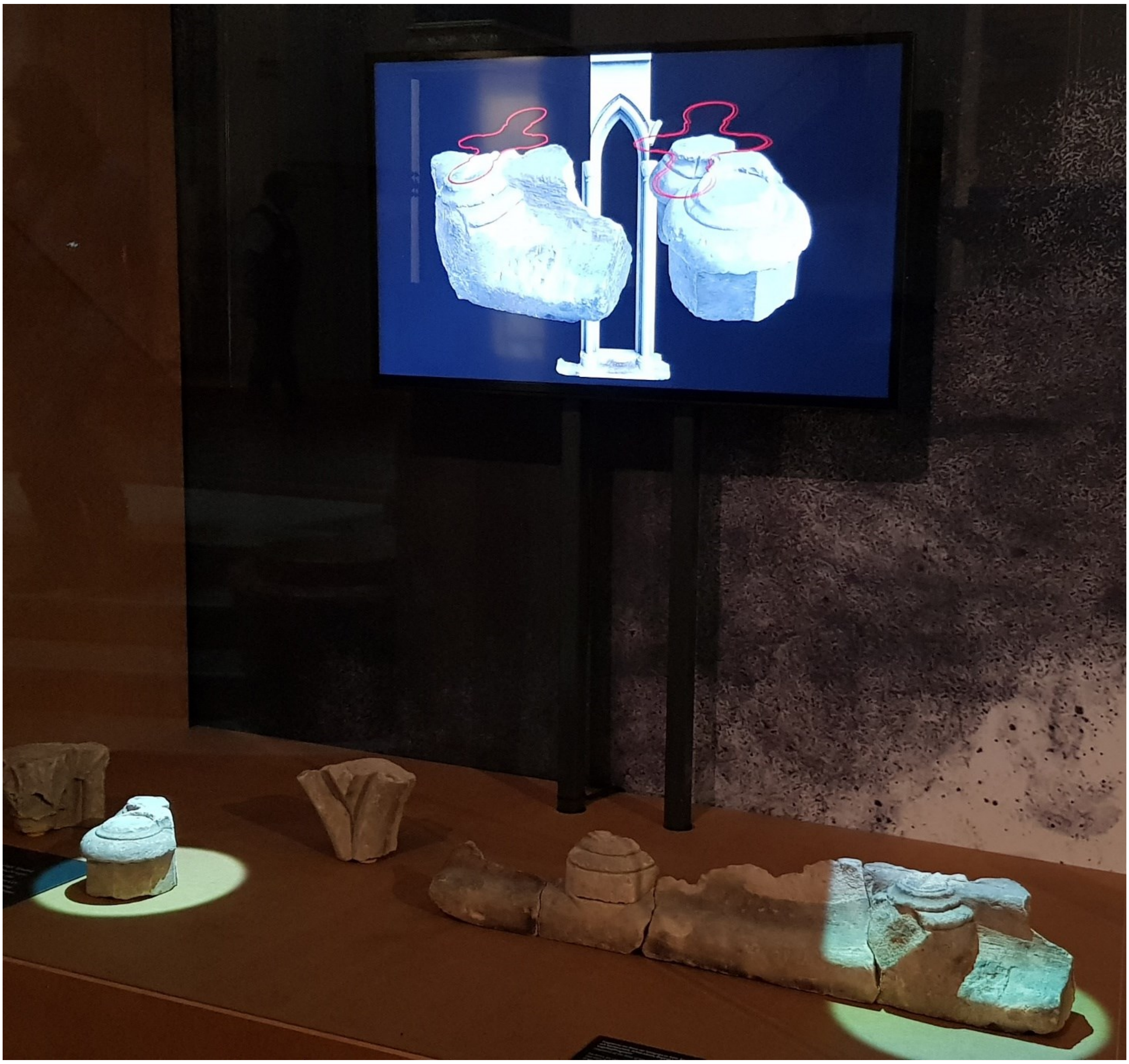

*Fig. 12. Installation of the virtual reconstruction of the bimah at Martin-Gropius-Bau 2019. (© Architectura Virtualis, Cooperation partner of TU Darmstadt)*

## Concluding Remarks

Working on this project has highlighted just how much scholarly reconstructions benefit from the digitisation of archaeological features and finds. Possible solutions and variants can be arrived at and crosschecked with greater ease. Moreover, digitisation has enormous potential in the presentation of findings. The three-dimensional visualisation of finds, features, and their interpretations brings together different forms of knowledge in an immediate and compelling way that allows viewers to follow complex lines of arguments. Furthermore, rapid prototyping has the potential to create haptic models of archaeological or architectural features that can become projection screens for more detailed information on the site or its history over time. The example of the bimah illustrates the potential inherent in the mutually enhancing presentation of virtual reconstructions and original objects in a combined exhibit.

The members of the project team seek to forge new ways of presenting virtual reconstructions. Particularly in exhibitions, two very different expectations must be reconciled. On the one hand, the museums, audiences and colleagues involved in the field want to see a scholarly and scientific approach to reconstructions, on the other, audiences call for comprehensibility, immediacy and atmospheric images. In this project, it was tried to develop a differentiated visual language that would satisfy all those demands. In the representation of the Jewish quarter and in the derivation of the reconstruction of the synagogue, we have worked with a dual visual aesthetic. On the one hand, the bird's-eye perspective views follow a comic-strip-inspired graphic style that underlines the reconstructive and hypothetical nature of the image (Fig. 2, 5, 8–10). On the other hand, the films feature atmospheric tracking shots from a pedestrian's perspective (Fig. 3, 4, 11).

To satisfy the demand for scholarliness, the decisions informing and driving the reconstruction process and the results and findings are recorded in a documentation tool for virtual reconstruction co-developed by the team in Darmstadt (www.sciedoc.org) (Grellert et al., 2019; Pfarr-Harfst and Grellert, 2016). A first publication of the Cologne project in this tool is planned for 2021.

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# Best Practice Checklists for 3D Museum Model Publication

## Quality Chart for Museum Photogrammetric 3D Asset

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Arnaud SCHENKEL, ULB – PANORAMA, Belgium

**Abstract:** This article highlights good formatting practices in 3D assets publication and challenges the way those museums share this kind of content. Observations of more than 200 assets have been made through various museums 3D models, uploaded in open access WebGL platforms and published on a large scale cultural recognized institutions official accounts to determine the best keys to judge the model quality requirements.

The produced checklists will take into account various specific criteria about the acquisition to the presentation of the final asset in the web viewers. The analysis grid first takes into account the topology quality evaluation by explaining the different relative problems encountered in mesh construction and treatments. The texture quality evaluation gives information about how to judge colorimetric and details aspects needed by a museum digital copy. PBR shader quality evaluation part intends to explain the different layers of a Physically Based Rendering shader and how to combine correctly and without confusion those layers to mimic the reality produced by the light incidence on an asset.

Those three first technical checklists are completed by three important presentation aspects leading to high grade 3D experience for the public: the lighting quality evaluation; the enhancement options and their utilities and the asset context.

Shortcomings are identified and explained for each table in order to improve the delivery process of digital reproductions. This quality chart through its six tables wishes to give a better knowledge of assets creation, especially if models are not produced by a specialised inhouse technician.

Online museum visitors, students or professionals need the best numerical reproduction quality to be able to perfectly understand all the complexity of a masterpiece as in reality, and even more by the ability to manipulate those digital objects and to observe them from every viewpoint.

***Keywords:*** *Practices—3D—Assets—Publication—Museum*

**CHNT Reference:** Guillaume, Henry-Louis and Schenkel, Arnaud. 2021. Good Practices Necessity on 3D on-line Museum Models Publications. Quality Chart for Museum Photogrammetric 3D Asset. Börner, Wolfgang; Kral-Börner, Christina, and Rohland, Hendrik (eds.), Monumental Computations: Digital Archaeology of Large Urban and Underground Infrastructures. Proceedings of the 24th International Conference on Cultural Heritage and New Technologies, held in Vienna, Austria, November 2019. Heidelberg: Propylaeum.
doi: 10.11588/propylaeum.747.

## Purpose of the Checklists to Enhance Public Museum 3D Assets Quality

The quality checklists are based on the observation of 244 models[1] - two assets by museum or official collection account, uploaded on open access WebGL platforms and published on their official accounts - and aims to evaluate the intrinsic (topology, texture, and shaders) and extrinsic (lighting, post-effects, and context layout) quality of 3D models taking into account the point of Bennett (2015). From this assertion, it is possible to analyse 3D models production workflow based on published results.

WebGL viewers, Real Time viewers or CAD software can deliver information through the analysis of the mesh. The checklist entries depend on the asset's final goal and must be discussed and validated before the acquisition beginning. The proposed quality charts deliver a global view of asset's purposes making and follow the quality asked in a linear workflow of game development and 3D cinematic rendering.

All the observations and findings define a complete specification chart aiming to specify at best the expectations of all the actors – museum and producers – in terms of world heritage collection publication. Through this article the analysis intends to give a better experience and scientific analyses possibilities for students and researchers who do not have access to the real artefacts. We divide the model quality checklist in six parts. Each checklist studies specific model specifications as validation steps.

### Topology Quality Evaluation

Mesh treatment, corrections, and aspects, reflecting its topology, are transcribed in Table 1. The checklist takes into account the size of the 3D asset into real world and details information: The model weight determined by the polygonal density according to its surface, the respect of its real dimension in a virtual space environment, its position into space (initial position and rotation centre), the surface cleaning process used to enhance the model (like denoising, smoothing, filling holes, outliers polygons cleaning) and the retopology requirements needed to alleviate the polygon count and adapt the texture (single or differentiated definition, limitation, or composite mesh).

- ***Mesh weight:*** It depends on the 3D player rendering capacity, the quality requirement and the viewing technologies (desktop, smartphone, ...). For a web purpose, the model needs to be as light as possible (best quality weight report) depending on its real size as explained in McGuire (2018). The delivery has to be tested with the generated texture and have to show any artifact before upload (ie: a statue nose over-decimated presents any relief at all). The decimation process must take into account the borders and the volume of the model to avoid any unfortunate deformations.
- ***Measure:*** The asset measurement needs to reflect the real subject. The size can be measured in CAD or into the WebGL player inspector. This data has to be precise when visitors use VR headset.

[1] The complete models list can be asked to the writer of this article because it is in constant evolution.

- ***Presentation into 3D space:*** The asset position into the 3D space needs to be assigned in the viewer back office: the asset has to be placed on its gravity centre, on the virtual floor of the viewer and in a natural position.
- ***Denoising:*** Depending on the camera sensor, the object material and the acquisition lightings, and the numerical reconstruction, the mesh can present some noise. When the asset needs to be very precise because it contains micro-topology, this noise must be polished in specialised software such as Meshlab, ZBrush, 3Dcoat or Rhino3D.
- ***Manifold**:* Some mesh presents artifacts such as scars, shrinks, distortions, tunnels, spikes, self-intersections or ripples also defined by Fei Dai et al. (2014) due to bad acquisition pictures or bad pictures processing. The corrections or mesh modifications must be written into the model description. In the case of 3D printing of the model, the mesh must pass through a *non-manifold* rectification process to avoid polygonal intersections.
- ***Mesh correction**:* Some models are presenting a lack of details or some missing parts due to a bad picture shooting coverage or an incorrect pictures processing. As for manifold observations, It is possible to correct those artifacts by taking more or better pictures, by applying picture corrections or by making a post-processing of the mesh before its publication.
- ***Filling holes**:* Depending on the subject and the pictures acquisition, some 3D mesh can present some holes. Those holes must be filled during the 3D post-production process.
- ***Retopology:*** It's a way to rationalize the topology of a subject to make it more suitable for its use or to be able to easily make some corrections in 3D post-processing. Movie productions (high standard) use *Pure Quad* mesh topology to let the shaders move correctly on the mesh while the subject surface is rigged/animated. The obtained photogrammetric topology could be transformed in *Tri*, *Quad* or *Ngon* (non-suitable). Some 3D players recreate automatically triangles from a *Quad* mesh topology just for speed rendering optimization dividing the quadrangles polygons by two.
- ***Normal inversion**: Normal* polygon inversion can cause wrong interpretation by CAD softwares or WebGL players (if in single-side projection) or discoloured polygons on the 3D asset surface. This kind of problem must be corrected to avoid viewing inconsistencies of the 3D model.

| Topology Quality | OK | NOK | Comments |
|---|---|---|---|
| Mesh weight | | | Under or over a reasonable number of polygons |
| Measure | | | Smaller than original / Greater than original |
| Presentation into 3D space | | | Gravity centre / Native position |
| Denoising | | | Smoothed mesh / Not smoothed |
| Manifold | | | Scars / Shrinks / Distortions / Ripples / Spikes / Tunnels / ... |
| Mesh correction | | | Lack of details / Missing parts |
| Filling holes | | | Holes filled / Not filled |
| Retopology | | | Triangle / Quad mesh / Ngons polygons |
| Normal inversion | | | Create hole where polygon normal is inverted |

*Table 1. Topology quality evaluation.*

The most common problems observed in these assets topological observations were principally the lack of retopology into quad mesh topology, practically any mesh corrections but also the presence of holes, shrink or noise and the lack of intentional decimation process. From those topological mesh observations, it can be defined that a lot of 3D museum collection assets are the result of a "*one pushed button*" automated photogrammetry process with practically any post-processing. Those productions can't lead to a multipurpose and correctable models: some of those errors depend on the photogrammetric acquisition process while others prevent any precise human rectifications on a topological view. In some cases, during this analysis, some museums published some new assets made by professional 3D agencies that passed all the requirements of our topological quality checklist.

### Texture Quality Evaluation

The colorimetric quality and the sustainability of this data presented in Table 2 are able to help a better stylistic comprehension of the real object and the possibility to have a better view on the corresponding craftship technique. This evaluation will be made on: the texture size according to a suitable texel ratio, definition and quality of the unfolding process and its usability (*UV Unwrap*, *UV mapping*, *UV packing* or the use of *texture atlas*), the respect of the real subject colorimetry, the presence of a delighting process (shadows suppression) and its implication in rendering (production of an *Albedo map* in addition of a *Colour map*) as well as the overall clarity in the 3D asset manipulations such as a zoom on particular model details.

- ***Colourimetry:*** photogrammetric assets colourimetry depends on the acquisition context and if the photographer used a colour chart to rectify the white balance and the colour tones during the post processing. The realistic colours rendering and the realistic light reactions depends on those rectifications.
- ***Pixel peeping:*** it's the ability to zoom on the asset without reaching blurry or pixelated texture. The texture definition depends on the texel ratio and the choice between quality and rendering time of the real-time renderer. Museum asset texture must be sharp when zooming in to be perfectly understood and studied.
- ***Rectification:*** texture maps may have been rectified or modified in 3D post-processing. For this purpose the asset maker has to check if there are no differences between the texture

layers, for example between colour/albedo maps and normal maps. Each asset must be verified for seems presence, artifacts, blurry parts coming from bad photography focus, flying polygons or uncoloured parts.

- ***Reprojection:*** the camera photogrammetric reprojection creating the asset texture is judged by observing presence of texture misalignment causing blurriness or doubling details between the mesh and the texture.
- ***Unlighting:*** if shadows persist on the colour map, the texture was not properly delighted and cannot be realistically relighted by the 3D rendering process.
- ***Unwrap quality:*** the unwrapping process develops in 2D the 3D asset texture such as a taxidermy. By this process, the operator produces a humanly understandable picture that can be rectified in CAD software. Without this step, it will be practically impossible to rectify the texture ad posteriori due to the deformations and the subdivisions in the texture.
- ***UV mapping / packing:*** UV mapping and UV packing are reorganisation of the islands (texture patches onto UV surface) composing the asset texture in a 2D representation. It intends to optimize the space through the size assigned to the texture and by the way it's definition (like 4K, 8K, 16K).
- ***Texel density:*** an asset couldn't have the same texel density all over its parts but it's possible to increase or decrease the scale of the UV texture parts called islands. Increasing the scale of an island gives more definitions to certain texture parts of an asset, giving more importance to some detail parts.

| Texture Quality | OK | NOK | Comments |
|---|---|---|---|
| Colorimetry | | | Realistic / Unrealistic |
| Pixel peeping | | | Blurry / Pixelated when zooming on the asset |
| Rectification | | | Seems / Artifacts / Blurry parts / Uncoloured parts |
| Reprojection | | | Reprojection inconsistency / Misalignment |
| Unlighting | | | Unlighted / Not unlighted |
| Unwrap quality | | | Humanly understandable / Raw from software |
| UV mapping / packing | | | Organised / Not organised / Mesh cut |
| Texel density | | | Respected or not (2k, 4k, 8k, 16k) |

*Table 2. Texture quality evaluation.*

Concerning the textures quality, the 3D models analysis reveals some recurring problems : usage of blurry pictures or misalignment during the photogrammetry process introducing blurry parts in the generated texture, UV Unwrapping process with no real texel ratio to conserve the highest picture definition, too few texture post-rectification in CAD software but also the use of low texture definition giving pixelated or blurry rendering texture when zooming into the models details. Some of those problems came from a lack of filtering or post-processing before the picture importation into the photogrammetry software or just an optimisation process misunderstanding on how to prepare and correct a 3D model.

### PBR Shader Quality Evaluation

This part of the quality checklist looks at the appropriate presence and use of the different texture maps used for creating a realistic rendering experience. The grid takes into account the subject's materials and the light influences to look how artefact materials interact in the real world but also some effects based on those materials. As defined in Deshmukh et al. (2017) real-time renderers use, Physically Based Rendering (PBR) shaders require several specific maps in order to fully render the appearance of the subject into realistic experience. Production of those necessary maps depends on the real materials subject in order to provide to the shader the information needed to work properly. The lack or the erroneous uses of those texture maps in the shader configuration will obviously imply an uncontrolled data or a confusion in the rendering player. To perfectly understand how works the layer construction of a shader, it is necessary to explain each one:

- ***Albedo map:*** need the presence of a real Albedo Map. The Albedo map is the Diffuse map – the camera reprojected texture – without shadows (underexposure) and hot spots (overexposure). It can be obtained by using cross-polarisation acquisition technique, by treating all the pictures by removing highlights and shadows or by delighting the photogrammetric obtained colour map in a software such as Agisoft De-Lighter.
- ***Geometric normal map:*** presence or not of a geometric normal map such as explained in Glassner (1990) generated by extracting geometric information from the High-Definition model shape. The normal map uses RGB information corresponding to the X, Y, Z axes in 3D space indicating the exact direction of the normals of each element and its orientation indicates how the shading should be performed.
- ***Texture normal map:*** Normal map texture is extracted from the High-Definition model Albedo or colour Map. Definition is the same as the geometric normal map but the source of the information comes out from the details of the colour map texture.
- ***Blended normal map:*** Ameliorated normal map resulting from the combination of the geometric normal map and the texture normal map by blending those two maps. This crossover map contains the global relief information of the geometric model data blended with the micro-details contained in the texture map.
- ***Ambient Occlusion map:*** Ambient Occlusion (AO) map is a shadow simulation caused by objects blocking ambient light. It allows dark areas that are difficult to access by the light producing reliefs on the subject.
- ***Glossiness / Roughness or Metalness map*:** The Glossiness or Roughness map defines how the light rebound on the surface depending on its nature.
- ***Specular / Reflection map:*** Specular map defines the brightness and the highlight colour of a surface. The higher is the value, the brighter the surface will be. This map has to be hand painted depending on the reflexion of the materials on the subject.
- ***Cavity Map:*** Cavity map represents dark shading in the crevices of a subject accentuating the details. The black parts represent the recesses and the white ones the high points.

- ***Transparency / Opacity map:*** Transparency or opacity map (Grayscale Relief Texture) defines the material transparency level. Those maps can be hand painted to give this propriety to some parts of a 3D model.
- ***Subsurface Scattering map:*** Subsurface Scattering (SSS) map defines the light penetration and the diffusion level inside a translucent material such as skin.

| PBR Shader | OK | NOK | Comments |
|---|---|---|---|
| Albedo map | | | Erroneous use of maps |
| Geometric normal map | | | Erroneous use of maps |
| Texture normal map | | | Erroneous use of maps |
| Blended normal map | | | Geometric + Texture Normal map blending |
| Ambient Occlusion map | | | Erroneous use of maps |
| Glossiness / Roughness or Metalness map | | | Erroneous use of maps / Uniform / Handmade |
| Specular / Reflection map | | | Erroneous use of maps / Uniform / Handmade |
| Cavity map | | | Erroneous use of maps |
| **Transparency / Opacity map** | | | Erroneous use of maps / Handmade / Uniform |
| **Subsurface Scattering map** | | | Erroneous use of maps / Handmade / Uniform |

*Table 3. PBR shader quality evaluation.*

Through the observation of the different analysed models, various negative points and shortcomings emerge such as a majority of assets published in PBR material mode only containing the Colour map without any Normal map – limiting real lighting simulation of the subject or reflecting details lost if the model is decimated – but also a real confusion between different maps composing this PBR shader:

- Confusion between Albedo map (colour without light and shadow) and colour map,
- Confusion between Metalness and Specular in PBR shader,
- Confusion between Roughness and Glossiness in PBR shader.

The major problems come from the misunderstanding usage of the PBR shader production.

### Lighting quality evaluation

The light incidence on a model and its visual presentation as a collection part in a museum and how the museum curator wants to present this digital model for the public is evaluated in Table 4. The entries explain the light quality though the selected shader type in the real-time render engine, the model lighting needs for its presentation, the use of different lighting types (spot light, HDRI, shadeless, etc.) implementation and complexity and the light impact on the subject rendering.

- ***Lit / Shadeless:*** WebGL players and real time renderer give the ability to enlighten assets scenery but also to produce lighting effects without any shade to offer a flat view of all the details. This point is a representation choice of the publisher and can be commented upon depending on the whole 3D Scenery offering to the visitor another way to understand the masterwork produced on the artefact without any shadow disturbances.

- ***Lighting rig:*** 3D renderer offers a very flexible way to enlighten scenery. Lighting rigs are composed, at least for giving a realistic representation, of a key light (direct light), of one or more fill lights (to model the shapes of the subject) and of one or more backlights to give consistency to the details. Each of those lights possess different colour temperatures to enhance the composition. WebGL players such as Sketchfab only offer three lights. The quality chart takes into account the use of those lights when such lighting is used.
- ***HDRI:*** another way to enlighten a scenery is to use a High-Dynamic-Range Imaging (HDRI). A HDRI is a spherical picture containing the whole lighting information made by stacking a wide range of aperture stops. It is possible to choose the angle of the lighting parts of this spherical projection and its intensity. It can also be used as a background or to make realistic reflexions and caustics on a reflexive material. Most of the WebGL players and Real Time renderer furnish common HDRI to illuminate 3D scenery. The chart takes into account the shadows quality resulting from a default or a specified purpose made HDRI, reproducing the real environment and the lighting of the artefact in its place in its own museum.
- ***Shadow catcher / Baked light:*** those two points represent technical points for loading time or for fluidity. Shadow catcher and backed light are pre-calculated shadow textures avoiding a real time process. Those techniques are used when in the scenery the subject lay down on a support or on the ground.

| Lighting Quality | OK | NOK | Comments |
|---|---|---|---|
| Lit / Shadeless | | | Lit / Shadeless |
| Lighting rig | | | Use of …. light |
| HDRI | | | Common / In House |
| Shadow catcher / Baked light | | | If there is support for the subject (ground, pillar, column, …) |

*Table 4. Lighting quality evaluation.*

The lighting quality of the whole 3D model composition has a drastic impact on its comprehension. Following problems which affect the representation of the observed models can be raised such as:

- The misplacement of the lights (spot light misplacement or HDR angle),
- The use of a default HDRI causing inconsistent or unrealistic shadows,
- The use of unlit scenery with texture already presenting shadows,
- The configuration of a wrong Shadow Bias.

**Post effect evaluation**

The global composition and rendering enhancement options within a WebGL 3D player such as Sketchfab2 gives the ability to enhance the model presentation with photographic filters and various effects in order to highlight its details or compose a staging to emphasize. Used wisely, those additional options and effects can significantly enhance the visibility of details or highlight a specific

[2] Sketchfab is a platform to publish, share, discover, buy and sell 3D, VR and AR content. It provides a viewer based on the WebGL and WebVR technologies that allows users to display 3D models on the web, to be viewed on any mobile browser, desktop browser or Virtual Reality headset.

presentation context. On the other hand, in some cases, they can hinder a good scan by digitized artifacts. The evaluation list is presented in Table 5 and describes the different effects and their impact on a model.

- ***Screen Space Reflection:*** Screen Space Reflection (SSR) is a technology to simulate lower quality reflections and to limit the specular light leaking. The use of SSR is logically limited for low configuration rendering. Its use needs to be justified because it was implemented for performance mode over quality.
- ***Screen Space Ambient Occlusion:*** Screen Space Ambient Occlusion (SSAO) is used to defer the Ambient Occlusion in real time and is taken in charge by the graphic card. If there is already the presence of a baked Ambient Occlusion in the shaders, this option is not needed at all.
- ***Sharpness:*** check the usage or not of the texture sharpening enhancement if it is needed. The lack of Sharpening could give a blurry texture details but if it is used too extremely it can produce noises or artifacts on the texture when moving around the model.
- ***Grain:*** this effect result inserts a film grain filter in the viewer. The quality chart considers that this kind of filter degrades the quality of the 3D work.
- ***Chromatic aberrations:*** result of inserting chromatic aberrations filter. The quality chart considers that this kind of filter degrades the quality of the visualisation.
- ***Vignette:*** Vignette is a reduction of the brightness or saturation towards the periphery to catch the eye on the model or on a particular detail of the composition. However, the use of vignette can harm the overall composition and particularly the background information.
- ***Bloom:*** this effect inserts a chromatic aberrations filter. The quality chart considers that this kind of filter degrades the quality of the visualisation.
- ***Tone mapping:*** tone mapping is a technique created to enhance the textures by offering a way to raise the dynamic range of the pictures. This option can be used to enhance the colorimetry, but used too low or too far, the model colours will be degraded.
- ***Colour balancing:*** this option permits colour rectification directly in the real-time renderer. When the base colour is not rectified in post-production, this effect is able to more or less do it. The chart takes into account a comparison between the non-optimised colour map and the real-time renderer post-treatment result.

Enhancement can be needed to compensate deteriorated quality generated by the real-time rendering engine or by an unwanted texture compression. However, it is clear that some effects, in some cases, are improperly used such as:

- Too much sharpening causing noises or artifacts when moving into the scenery,
- Use of grain, chromatic aberration and bloom effects altering the colorimetry and the real aspect of the model,
- Need of tone mapping or colour balancing tweaking to manage colorimetric problems.

| Post effect | OK | NOK | Comments |
|---|---|---|---|
| Screen Space Reflection | | | Useless (backed AO map) |
| Screen Space Ambient Occlusion | | | Blurry / Sharp / Too sharp |
| Sharpness | | | Useless / Too much |
| Grain | | | Useless / Too much |
| Chromatic aberrations | | | Useless / Needed |
| Vignette | | | Not necessary / Too much |
| Bloom | | | None / Too much |
| Tone mapping | | | None / Too much |
| Colour balancing | | | Useless / Too much |

*Table 5. Post effect evaluation.*

### Context evaluation

Production quality also takes care of archiving each step of the work in order to be able to use the raw files and the intermediate data to improve a model ad posteriori, either to correct it or to complete it. 3D rectification gives a guarantee of compatibility through numerous modelling software and rendering engines or for different publication types but a model is nothing without context. Table 6 provides the information needed to complete the 3D models presentation context:

- ***Background:*** the presence or not of a specific background designed for or by the museum containing its logo and some contextual information. The background can be a 2D picture or a spherical one (HDRI) representing the real place of the subject in the museum room.
- ***Reproduction authorisation(s):*** presence of an annotation in the description part announcing if the 3D acquisition of the model was made with or without the museum authorisation.
- ***Official model:*** a text describing if the model presented is the original one or a 3D acquisition of a reproduction.
- ***Author(s):*** presence in the asset description of the artist attribution and a production date.
- ***Collection name:*** if the model is a part of a particular collection, does the description cites this one?
- ***Description:*** copy of the museum description card linked to the artifact if it is an official museum asset. This pasted description of the model is under copyright law. When the 3D model is not the museum propriety, this text needs a reproduction authorisation.
- ***Inventory number:*** presence or not of the museum inventory number in the description.
- ***Picture(s) in place:*** presence if possible, some real pictures of the real model in context.
- ***Place in the museum:*** localisation inside the museum building offering the possibility to visitors to rapidly reach the original subject seen in the 3D library.
- ***POI('s):*** integration or not of interactive Point of Interest (POI) in the 3D scenery.
- ***Credit(s):*** insertion in the asset description of all the credits such as photographer, 2D and 3D artist(s), etc...

| Context | OK | NOK | Comments |
|---|---|---|---|
| Reproduction authorisations | | | Authorised / Proprietary / No authorisation at all |
| Proprietary | | | Piece of the museum collection or not |
| Official model | | | Reproduction or original |
| Author and era | | | Attribution of the subject |
| Collection name | | | If part of a specific collection in the museum |
| Description | | | Historical and archaeological description of the subject |
| Inventory number | | | Related to the museum collection |
| Picture in place | | | Original picture of the subject |
| Situation in the museum | | | Room in the museum |
| POI | | | Presence of POI on the model |
| Credits | | | Credits of the photogrammetrist and/or 3D artist / 3D Society |

*Table 6. Context evaluation.*

The context checklist is made on a global observation of lacking information in model descriptions and in order to present some possible entries to add on each 3D asset. In this case, it is more of a checkbox list than a statement on the 3D models quality referenced during these inspection sessions. Nevertheless, this information makes it possible tot judge the attention paid to the subject and to the creation of its digital reproduction.

## Conclusions

Defining a quality chart based on intrinsic and extrinsic criteria of 3D museum models forces in a first step to review all the important points of the PANORAMA platform production pipeline for improving the internal quality of the assets made within the framework of research projects. In a second time, it offers to structure the photogrammetry training course initiated at the Université libre de Bruxelles in September 2019 and to adapt the different workflows for obtaining an easy way to produce 3D photogrammetric models by the students who never touch 3D software.

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# Designing the Past (Together)

## On the Gaming Industry's Contribution to Archaeology and What We Can Contribute to the Gaming Industry

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**Abstract:** Video games have become one of the spearheading media forms of the 21st century and their impact on our society omnipresent. Many games do represent historical and archaeological pasts in an artistic manner that leads still to wide criticism among archaeologists, historians and heritage practitioners as these reconstructed pasts do not represent the scholarly complexity that academia provides. Nevertheless, attempts to bridge the digital gap between academia and the public are still conducted even though they remain often fruitless due to the lack of effective understanding of popular audience expectations. Since recent years the gaming industry started to address the demand of their consumers for more authentic reconstructions of ancient towns and past societies. Because of that academic specialists have been increasingly employed or outsourced to enhance the quality of their games. This paper aims to discuss this development and interrogate aspects of it from an archaeologist's perspective. For that, cases are presented in which illustrate the relation between archaeological knowledge and the processing of it through games. It shall be also further discussed why it is crucial to participate in this process to benefit from an interdisciplinary collaboration between archaeologists and the gaming industry. It shall be not of focal interest to address the flaws of games in representing complex pasts but rather how to formulate an approach that would satisfy the industry as also archaeologists.

***Keywords:*** *Digital Archaeology Game Studies—Media Archaeology—Theoretical Archaeology—Archaeogaming*

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## Introduction

Archaeology's association with media and video games has never been satisfying for most archaeologists. This may go back to the fact that figures like Indiana Jones or Lara Croft had developed "the idea that archaeologists slash through jungles and prowl through caves searching for golden idols, precious work of ancient art, and magical charms" (Orser, 2015, p. 113). The obscured expectations towards the work of an archaeologist which are presented to the public may be one issue. Another aspect that has been always discussed by archaeologists and historians as well, is the accuracy of the content that is presented in digital games; to which extent can the past be generalised, what are the repercussions or does it even matter? (Chapman, 2018; Reinhard, 2018). The visualisation of past realities into which people can immerse themselves became “increasingly significant in tourism, entertainment and education” (Petersson and Holtorf, 2017, p. 3). Hence video games like the *Civilization* series or the *Assassin’s Creed* series have been trying to offer past experiences to a growing community of players. These games do not just let players immerse into historical events but they also visualise a material past based on archaeological evidence. The representations and reconstructions of material heritage have huge implications for our society and its collective memory as most children grow up playing video games already at an early age.

The direction in which the archaeological framework develops has been always influenced by socio-cultural realities (Trigger, 2007) and therefore it has been only natural that many scholars like Angus A. Mol and Andrew Reinhard had been discovering the conjunctions between archaeological science and video games since recent years. While Reinhard tried to explore how to apply an archaeological methodology on digital games (Reinhard, 2018), the *VALUE Foundation* has investigated on how video games could be used for didactic purposes in the context of heritage and archaeology (Mol et al., 2017a).

However, an understudied aspect remains how archaeologists can effectively participate in the visualisation of past realities for the public. Cooperation between archaeologists and the gaming industry could have immense benefits for both sides. The paper aims to address the possibilities and chances of the cooperation between archaeologists and the gaming industry to forward a progression on the field of a digital Public Archaeology. To accomplish that a recapitulation on video games that visualised the past for the last two decades is necessary. For that various cases were chosen to illustrate the different aspects in which video games can represent the past. Further, the game industry’s contribution to archaeology will be pointed out. For this reason, three factors that mark the industry’s contribution are going to be discussed further, namely: a vital interest, the visualisation and an object of study. The vital interest consists of the awareness about the past that is transmitted by video games to the public, the visualisation consists of the 3D-reconstructions of ancient sites, monuments and material culture that is being utilised for the prior factor and the object of study is the game in itself which can be seen from the perspective of contemporary archaeology as part of nowadays digital culture (Reinhard, 2018, p. 59) For that Civilization 6 was selected to illustrate the aspect of the game industry’s contribution.

After that, a similar approach will be conducted to define the potential contributions of archaeology to the gaming industry. The factors that will be discussed in this section are content, inspiration and integrity. The first two factors are passive in being able to be exploited by the gaming industry without having an archaeologist involved while the third one is an active factor as an archaeologist needs to be involved to offer archaeological integrity to a video game. In the case of content, every bit of knowledge about archaeological heritage is meant. From which function the buildings in the Agora of Athens may have had to how a Roman Legion under Emperor Claudius might have looked like. Inspiration is a factor that defines trends in the gaming industry. Inspirations for games that visualise the past are ambivalent and can evolve from either a lack of archaeological evidence or an abundant amount of archaeological evidence (How did Life in the late Palaeolithic look like Vs. How did life in the early Roman Empire look like)? Important to add is that those two passive factors can become active by the involvement of an archaeologist in preparing content and inspiration for game developers. The third factor which is purely active is the scientific integrity that video games can get by involving an archaeologist in their development. To illustrate this section the game *Egypt: Old Kingdom* was chosen. This game offers a perfect example of how the cooperation with specialists Egyptologists can look like and improve the quality of historical or archaeological pasts in a video game. The section will be dedicated to a conclusion with further prospects.

## A History of Playable Pasts

Since Hesiod works have been passed down to us that have somehow imagined and simulated a past with their causal present (Renfrew and Bahn, 2016, p. 22). While Hesiod chose to enclose his idea of a past in one of the most effective media at that time, which was literature in the 8th century BC, containers of conceptions and information have much changed in the following millennia. The industrial revolution gave birth to numerous technological developments of which photographs, audio and film have pushed the boundaries of the reproducibility of mass media (Benjamin, 2011). With the advent of cybernetics and computer sciences, connections and compositions became paradigmatic (Wiener, 2000). Finally, giving birth to the Leitmedium of the 21st century, the digital game (Muriel and Crawford, 2018). An interactive composite medium, containing intermingled audio, images, video, and text; all imbedded in binary code (Reinhard, 2018, pp. 12–13).

Like Hesiod almost three thousand years ago, many people throughout history and still now simulate a past to stimulate the present. The amount of video games that are simulations of (or at least related to) factual past events is innumerable. But visualisation of the past by video game developers does not come by chance. What we see is a visualisation of the past based on factual archaeological evidence; certainly, disobedient to the archaeologist (Clack and Brittain, 2007, pp. 12–13). One just needs to think about what impact the emergence of antiquarianism in the 17th and 18th century had on the fine arts, how the exploits of the Napoleonic campaigns in Egypt inspired painters and artisans (Trigger, 2007, p. 60) and how Schliemann's, Evans' and Carter's expeditions enchanted generations of Filmmakers. Since the PC revolution in the 1990s and the smartphone revolution around 2012 (Twenge, 2018) digital games have advanced deep into private households and private lives of billions of individuals. Digital games are not only accessible at any time for the majority of all human beings but also already undoubtedly a major player in our culture and education. For western generations that were born in the late 1970s, there was hardly any childhood without having ever played an arcade or video game (Barton, 2008, p. 44). It can be therefore said that the earliest conceptions about our world and its causal relation to an apparent past are developed through the intensive activity of gaming. Much of the media we consume, especially at an early age, mould itself into a solid framework of how we perceive our world and its supposed past.

### Age of Empires II. (1999)

*Age of Empires II: The Age of Kings* is a real-time strategy game that is thematically placed in the Middle Ages. The game was released in 1999 as a sequel to its predecessor and stands still as a milestone in PC gaming history. The game offered the player in an open narrative style the possibility to engage into historical campaigns involving the exploits of King Barbarossa or Genghis Khan or into varieties of single-player and multiplayer based skirmishes. The player has in all modes of the game to choose between various cultural entities which come with different traits. While the Vikings have strong longboats, the Japanese can train the Samurai, which are one of the strongest elite troops of the game. Throughout the game, the player will have to manage resources, construct buildings and defences (see Fig. 1). One will also need to train and organise troops to survive onslaughts of the enemy that one may strike back and defeat the enemy at last. Throughout AoE2 the player will encounter diverse cultural visualisations of military units and architecture associated with their specific attributes and values. While the game is certainly anachronistic, it is not ahistorical (Chapman, 2018, p. 236). It is a rather counterfactual and conceptual medieval past.


*Fig. 1. Managing your camp and its resources in Age of Empires 2 (CC)*

### Titan Quest (2006)

*Titan Quest* is a role-playing hack-and-slay video game that is thematically placed in a mythological anachronistic classical antiquity, including locations as Greece, Egypt, Mesopotamia and the Far East. The game is still remembered for its outstanding graphics in 2006, innovative gameplay and thematic concept. Throughout the game, one visits different antiquities and ancient landscapes to bring order to a world in which mythological creatures have taken a toll on the human world. The player fights creatures from different mythologies. While the player faces hordes of satyrs, cyclops and centaurs in Greece, he encounters different mythological equivalents in other geographies. Even though the focus of the game is on the fictional storyline and the slaying of hordes of monsters, it is visually comprehensible to the player that he is moving through different cultural landscapes. The aesthetics, weapons, architecture and mythological creatures were designed with much detail to create contrasts between the different cultural landscapes. Through this contrast, the player learns the similarities and differences in architecture, weapons and mythology of ancient cultures. The visualisation of this fictional past is for sure not without any flaws and offers only a longue dureé capture of the recreated cultures (Chapman, 2018, p. 239). Meaning that architecture and weapons from different periods are mixed and the representation of Egypt, for example, is only a fused accentuation of many periods in its cultural, militaristic, mythological, and architectural history (see Fig. 2). Nevertheless, the player will develop a conceptual intuition of important cultural and mythological aspects of the ancient world and differences between various cultural units namely, Greece, Egypt, Mesopotamia and the Far East. This conceptual knowledge is solidified through the role-play aspect in which the player spends much time in equipping his character with different kinds of weapons and arms that bear specific cultural aesthetics.


*Fig. 2. Encountering significant features of ancient Egyptian's visual culture in Titan Quest (CC)*

**Assassin's Creed: Unity (2014)**

*Assassin's Creed: Unity* is an action-adventure game with stealth elements. The game is part of the *Assassin's Creed* franchise, one of the most successful game series in the history of video games (Komel, 2014, p. 74). Games of the series have been since years used as cases for many scholarly analyses in the fields of history and archaeology (Kapell and Elliott, 2013; Mol et al., 2017a;

Chapman, 2018; Reinhard, 2018). This comes not by chance; Games of the series have always provided exceptional digital reconstructions of towns and cities of various periods. By now stretching from the 5th century BC until the 19th century AD. These reconstructions have always been a playground for discursive approaches of historians and archaeologists, and in the same manner does *Assassin's Creed: Unity* serve here as a case. The game takes the player into the times of the French Revolution. The focal point of the game is an unbelievably detailed 18th century Paris. The game contains an iconic digital replica of the Notre Dame de Paris. After the partial destruction of the actual monument in 2019 the developer of *Assassin's Creed: Unity*, Ubisoft, offered its game for free to the public as a compensation for not being able to visit the actual monument (see Fig. 3). Anyhow, different from the previous two games Unity engages its player more immersively into the historic context through its game design. Mainly because of the player's perspective. While *Age of Empires 2* and *Titan Quest* had a bird's eye view on the actions taking place, Unity transports its player into a third-person view; looking the character over his shoulder and experiencing a Vitruvian proportion to the surroundings. Architectures and landscapes have hence a more impressive impact on the player. The game has an open story structure in which certain freedom is given to the player in being free to move through the in-game world as one pleases and to choose the structure in which one engages into the main storyline.

*Fig. 3. While the real monument remains inaccessible (upper image), why not visit the Notre-Dame in Assassin's Creed: Unity? (lower image) (© B. Hanussek)*

Creative pasts of ancient worlds offer a great deal of modern world escapism, entertainment and education. This paper was able to briefly wrap up three impactful games that have served millions of people with such: escapism, entertainment, and education. Still, the amount of games on past realities is growing almost daily with an apparently never-ending demand for more untold stories or innovative perspectives towards the past. The quality of these games is also progressing as the gaming industry is a highly competitive and unforgiving market. Yet, while increasingly better graphics and gameplay can be ensured by game developers themselves better historical content or thematic and conceptual depth are developments in the gaming industry that are starting to become outsourced. On the other hand, one shall not neglect the gateway drug these games have provided for people who advanced further into digging deeper into actual archaeological and historical records, sometimes even ending up studying archaeology or history (Hunt, 2004, pp. 94–95). The following sections will take a closer look at these developments.

## On the Gaming Industry's contribution to Archaeology

It may be evident that the gaming industry will not help archaeologists to excavate more effectively or create more accurate results on ancient demographics. The benefits for archaeology in this relation do not primarily lay in the lab or field, even though excavation simulators would be for sure a reasonable thing to develop for students (Reinhard, 2018, p. 17). The primary benefits are to be found on a public archaeological and theoretical basis. Even though academic discourse has highlighted games and their benefits for heritage, archaeological and historical practice, these benefits stay mostly vague and undefined. Hence this section will conceptualise three benefits as measurable entities.

### Interest

The Cambridge Dictionary gives us a simple but overarching definition on the concept of interest: "the feeling of wanting to give your attention to something or of wanting to be involved with and to discover more about something". It is undeniable that media of all kinds has done exactly that with archaeology. One just needs to compare figures and statistics. It is difficult to believe that the exponential growth of archaeology students between the 1990s and 2000s have nothing to do with the emergence of Indiana Jones movies in the 1980 and the generation(s) that grew up with the movies. Not to speak of the general growth of archaeological TV series in the second half of the 20$^{th}$ century. A similar trend may be observable in the visitor statistics of the Viking Ship Museum in Oslo. While visitors were significantly decreasing until 2013 the subsequently launch in that year and international success of the series Vikings has brought a sudden and continuing increase in visitors since 2014. A digital game has a similar impact on its players; maybe even more impactful. While people may read a book about ancient Rome or see a movie on ancient Egypt, players live and dwell in a virtual environment (Reinhard, 2018, p. 103) which can make them fond of an ancient Greece for example. So, the interest in archaeological or historical knowledge and practice is not just at hand but also more intensified through the immersive act of gaming (Muriel and Crawford, 2018, p. 91). Therefore, it can be said that the gaming industry generates interest which is a benefit for archaeology.

### Visualisation

It is hard not to be impressed by the yearly improving quality of game design and graphics that the industry is being capable of developing for its consumers. The latest *Assassin's Creed* games, Origin and Odyssey were and are an ongoing revolution in the development of a digitally reconstructed antiquity. These and similar games are determining how new generations of players imagine antiquity and ancient civilisations. Meanwhile, the ongoing autonomous attempt of archaeologists in trying to master the art of digitally reconstructing ancient sites by themselves to engage locals, tourists and themselves (Averett et al., 2016, p. 14) is happening but by far not satisfying in terms of design and graphics (see: virtual artefacts and digital reconstructions in archaeological museums and excavation websites). Therefore, it makes sense to look elsewhere for appropriate digital reconstructions for public outreach. The game industry does not only provide experts with years of experience but also the fiscal means to design vivid ancient towns that encourage the player to spend more time with her or his virtual surroundings, which most likely will increase an intuitive understanding of a past society and generate more interest (Copplestone, 2017, p. 89). Therefore, it can be said that the gaming industry produces visualisations that are a benefit for archaeology.

## Object of Study

This essay is already speaking for itself. Since the Atari Video Game Excavation (Reinhard, 2018, p. 23; Ruffino, 2018, p. 88) digital games have received quite reasonable attention from archaeologists and are increasingly discussed with various approaches. Digital games seem to challenge archaeologists to reflect on themselves, on how they as scientists, and how the cultures they explore are represented. Approaches like Reinhard's archaeogaming even use digital games as a playground for theoretical archaeology; working with game patches as stratigraphical layers. Digital games are of course also seen as a chance to revive the decreasing public interest in archaeology. But to understand the mechanisms of games and how they can be used for the benefits of a modern archaeology, games need to be studied, analysed and critically interrogated further by archaeologists. Therefore, it can be said that the gaming industry produces an object of study which is a benefit for archaeology. This benefit will not be highlighted further throughout the paper as the following games will be already treated as objects of study which will be self-explanatory for this aspect.

### Civilization 6

*Civ6* is a turn-based strategy game in which the player develops a civilisation "from the stone age to the information age" (Mol et al., 2017b) and competes with other civilisations for victory. Victory can be achieved through different kinds of gameplay. Military domination, cultural or religious hegemony and scientific supremacy are the common ways. Throughout the game, the player encounters "long-term planning and (…) evolution-like, phased gameplay. (…) [also] [t]he player will manage resources and make political decisions" (Mol et al., 2017b, p. 214) The whole Civilization game series has since the early 1990s already managed to steer much interest for past cultures and their technology-based development. To solidify the interest, every Civilization game offers a "Civilopedia" with entries on various aspects of the game. "These not only provide descriptions of in-game effects, but also provide information about the actual history underlying every building, wonder, unit, leader, technology, and more" (Mol et al., 2017b, p. 214). The many discursive works of historians and archaeologists also often state how this game has reinforced their interest towards an interactive past and shows that further interest is being generated and reinforced. Nevertheless, while interest is being factually solidified for its millions of players, it is also being enhanced by artistic visualisations. Each civilisation has an own historical leader (in *Civ6* also mythical with Gilgamesh from Sumeria), specific architecture and characteristic units. The visualisation of Civ6 has been largely criticised by the gaming community for its cartoonish design and overall lesser historic aesthetic (See: Steam User Reviews 2019) which may indicate that the demography of people playing games like civilisation relies on games like *Civ6* to appease their interest for an accurate playable past. It is interesting to see how a loyal community as the one that the Civilization series has felt deeply offended in being offered a game that did not focus on designing a realistic/serious past but rather an aesthetically inclusive and colourful one (see Fig. 4). Nevertheless, especially younger players found the game very accessible and for sure will be influenced by the game's visualisation of past cultures.


*Fig. 4. Cartoonish aesthetics in Civilization 6 (© B. Hanussek)*

The benefits that the gaming industry can and does create for archaeology are intriguing but still understudied. This section, therefore, may have offered an approach in conceptualising these benefits to make them observable and through the elaboration of these concepts technically measurable. Measuring the impact of digital games and their influence in shaping the understanding of archaeology, the past and heritage of the public exceeds this theoretical outline but can be done with the extension of the definitions using specific parameters and the borrowing of instruments of social sciences.

## On Archaeology's contribution to The Gaming Industry

Looking at character's like Dr Jones and Mrs Croft one might have the impression that the mass-media sector has already got all they wanted from archaeology; and that without even having to deal with actual archaeologists. Yet even though the commercial successes of these imaginary archaeologists are undeniable, times have changed and new generations have emerged. Marketing has become much more labour intensive for the industry and compelling content of media must be complex, deep and authentic. Games like *Assassin's Creed: Odyssey* or *Hellblade: Senua's Sacrifice* were in gaming history pioneering developments. The employment of academics into the staff of game developers has been an emerging trend for game developers that seems to be more than fruitful. While game designers can rather focus on their proficiencies in programming, specialists of all kinds of fields, mostly though from history and psychology, are employed to create deeper virtual environments. These environments are more authentic and offer through their conceptual depth a stronger immersive character. The result of such endeavours is excellent ratings for the games, a satisfied community and more time spent in the game by the players. It is hard to imagine any other science than archaeology that is more capable of adding more detail to the development of a game that represents a past. The benefits archaeologists could add to the development process are many but the most basic, yet most important for the gaming industry are for sure: inspiration, content and scientific integrity.

### Inspiration

"The past slips from our grasp. It leaves us only scattered things. The bond that united them eludes us. Our imagination usually fills in the void by making use of preconceived theories. (…) Archaeology, then, does not supply us with certitudes, but rather with vague hypotheses. And in the shade of these hypotheses, some artists are content to dream, considering them less as scientific facts than as sources of inspiration" (Lippman, 1986, p. 155). Looking at digital games it is obvious that the uncertainty about ancient cultures can offer as much inspiration as the certainty we have about others. Unfortunately, it often takes many years until novel archaeological perspectives escape the academic audience to the non-specialist domain. Having archaeologists with one foot in the industry and the other foot in academia novel perspectives on the past can be transmitted much faster. But also, these new narratives can be partly controlled by the scholar. It is not the developer who finds by accident a pseudo-archaeological book on ancient aliens but the archaeologist who supplies the developer with specific and bite-sized archaeological research which is transformed into inspiration. Novel information and unheard perspectives are valuable information in an industry that tries to sell stories. Therefore, it can be said that archaeologists can produce (controlled) inspiration which is a benefit for the gaming industry.

### Content

In-game content can be a storyline as also virtual landscapes, architectures and objects. It is a fact that a game that provides more detailed and complex content makes players more eager to keep playing it and explore its content further. Archaeological data which is theoretically mostly about preserving and interpreting landscapes, architectures and objects may find a visual and conceptual outlet in digital games. Yet, archaeological results, conclusions and reconstructions of the past are an undeniable heavyweight that has always posed difficulties in public dissemination. Nevertheless, archaeological data which can be transformed into immersive game narratives and virtual environments is at hand. If archaeologists are unhappy with the “inaccuracy or blatant misrepresentation” (Clack and Brittain, 2007, p. 23) they will need to offer themselves as an informant to the industry for content. But being capable of gathering data is only half the job. Hence, it must be the task of the archaeologist to understand the industry and the public and not the other way around (Holtorf, 2007, p. 12) to assemble what a game developer might be looking for. Also, the archaeologist needs to modify archaeological matters on a subject into a comprehensible story. The content must be transformed and not dumbed down. Therefore, it can be said that archaeologists can offer content which is a benefit for the gaming industry.

## Scientific Integrity

We live in an age of labels. Specialists of all kind produce labels for all kinds of products. It may be an association of dentists which approves of a certain kind of mouth wash or a human rights NGO that promises us that this coffee has been the result of fair trade. This kinds of securities and promises are crucial for consumers to make satisfying and mindful decisions towards the products they consume. These kind pedigrees have benefits for both parties. On one side the producer benefits from this kind of marketing and scientists receive acknowledgement and monetary resources for research. The ongoing trend of the gaming industry to employ specialists has proven much success not just in the game design but also in the promotion and marketing strategy of games. While historical video games would already successfully promote themselves as authentic and accurate (Chapman, 2018, p. 66) before specialists were employed to ensure these promises, games like *Assassin’s Creed: Odyssey* or *Hellblade: Senua’s Sacrifice* seem now to profitably ensure players about the authenticities of their games through the experts they have in staff. Archaeologists as experts on material remains seem therefore as an asset to any game that tries to represent a past. Therefore, it can be said that archaeologists can offer scientific integrity which is a benefit for the gaming industry.

### Egypt: Old Kingdom

In 2018 the Russian indie game developer Clarus Victoria released *Egypt: Old Kingdom*, a round-based strategy game that offers the player an experience of unifying Egypt and ruling its state through the historical epoch of the Old Kingdom. The game has a slight arcade-like character as it has predefined goals with key tasks (Unifying Egypt in a specific time, building a tomb for a specific king, etc.) that are evaluated according to one’s efficiency of achieving the objectives. The game was designed under close cooperation with the Centre for Egyptological Studies of the Russian Academy of Sciences (CESRAS) to ground the game design and narrative on archaeological and Egyptological evidence. The game is available for various platforms, has been purchased over 50,000 times and enjoys high ratings and a solid and active community (see: Steam Database, Google Play). Anyhow, what makes this game so extraordinary is that it works with archaeological uncertainties (Orser, 2015, pp. 52–54) The game does not offer a linear sequence of factual events that the player is just skipping through. It is the player that can choose a set up to play according to different accepted theories (see Fig. 5a). So, while one game mode accounts climate change for certain events, it is the invasion of a foreign people for it in another mode. But also, active decisions by the player can alter the course of the game narrative. For example, you can subdue, assimilate or annihilate another tribe to achieve the unification (see Fig. 5b). Each option needs different resources and alters again the course of the game. Another aspect that alters the game is how one researches technologies. Technologies are consecutive as some technologies cannot logically precede others, but again there is certain flexibility which works through the archaeological uncertainty of details (see Fig. 5c).

In addition to that, the visual representation of Egyptian culture is a creative extension of the original Egyptian canon. It does create vivid and new images, yet without exaggerating actual evidence (see Fig. 6a). It is visible that the Egyptologists and archaeologists who worked with the developers have provided important contributions in terms of inspiration, content and scientific integrity. Inspiration was certainly found in the creative use of archaeological uncertainties to create a non-linear and flexible game design that enables the player to experience different narratives of the Old Kingdom. Content can be found in the rich illustrated and commented segments of the game, which feeds the player with primary information to game relevant aspects but also with secondary facts to the ancient Egyptians in general (see Fig. 6b). Scientific Integrity is not just provided by the CESRAS but also accounted and utilised by the developer to promote the game. All in all, *Egypt: Old Kingdom* can be seen as a perfect case in which the cooperation between an individual game developer and an archaeological/Egyptological institution worked out. According to online reviews, the game seems to be fun and educative for players who do have little prior knowledge of ancient Egypt, as also enjoyable for professionals who enjoy revisiting accurate facts.


*Fig. 5. a) Defining theoretical frameworks for one's gameplay; b) Different ways to interact with in-game peoples; c) Advancing technologies according to one's gameplay (© B. Hanussek)*

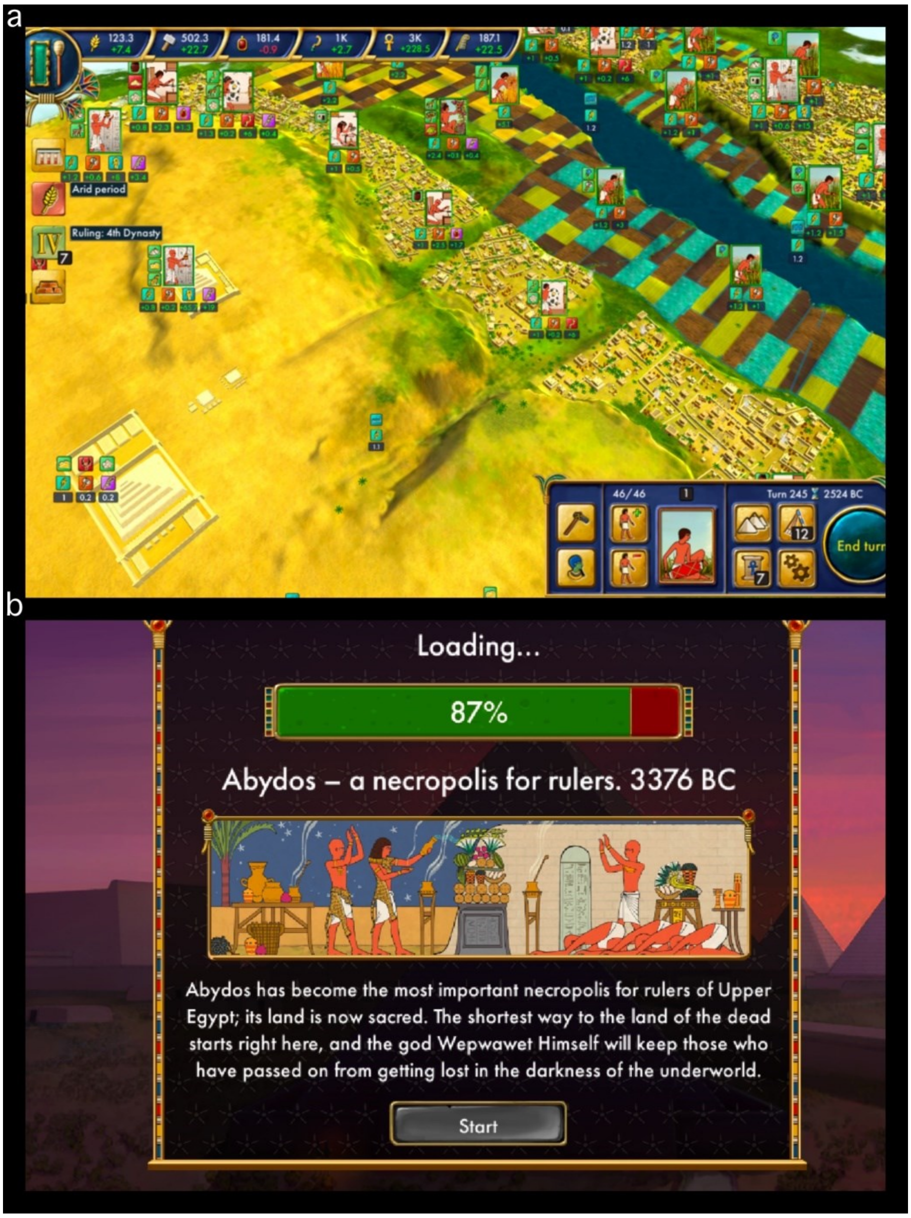


*Fig. 6. a) Basic gameplay overview; b) Egyptian quick facts on the loading screen (© B. Hanussek)*

## Conclusion

It is obvious that with the further development of immersive technologies, digital games will increase their presence and influence on our society and understanding of our world. Another part of this development which arises from the core of our neo-liberal society is the democratisation of knowledge. Looking towards the age of alternative media, fake news and decentralised authorities it seems questionable to still rely on traditional educational outlets to transmit fundamental scientific knowledge to a public that seems less, and less concerned with the rather smooth but complex developments inside the archaeological academia. Now, video games have come a long way since their technical infancy in the late 1960s. This kind of medium can visualise, conserve, transmit and consolidate effectively knowledge of all kinds. While the gaming industry may have exploited this fact for own benefits and painted a (for archaeology) debatable past for its players, the isolated attempts by archaeologists, heritage and museum practitioners in doing the same have turned out rather fruitless over the last two decades. Designing a compelling game has become a science by own means looking at the amount of game design and game studies programmes offered at numerous universities around the globe. Accepting that as a fact may make it easier for archaeologists, historians and similar scholars to see collaboration with game developers as a meaningful interdisciplinary endeavour rather than a subduing process of dumbing down factual knowledge about the past. The game *Egypt: Old Kingdom* offers a brilliant example of how first steps towards a beneficial relationship between scholars and game developers can look like in crafting an interesting, visually appealing and fun experience in an authentic past.

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# Hypothetical reconstruction of a late ancient residence at Podunajské Biskupice

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**Abstract:** The remains of a late ancient Germanic residence dated to the last third of the fourth century AD, unearthed at the location Križovatka in the cadaster of the village Podunajské Biskupice at the end of 2017 and beginning of 2018, is one of the most unique discoveries in decades. The archaeological excavation unearthed the remains of a Germanic residence, which formed part of a larger settlement. The size of the excavated area was around 48 × 58 m. The residence was enclosed by a wooden fence, which went into the depth of 40 cm from the point where it was recorded. The inner structure of the farmyard was formed by six wooden rectangular buildings, whose foundations have survived in the form of trenches and postholes. Stone was used only to support the columns of the portico in Buildings I and III. The architecture of the residence differs from the standard Germanic settlements, which have buildings with halls or sunken-featured pit-houses. Aristocratic residence in Podunajské Biskupice is built in wood, but its overall layout, the principles of symmetry and axiality predetermining the arrangement of the buildings, and the large square colonnade buildings are architectural features and principles rooted in the tradition of ancient architecture. It seems that both the architect who designed the complex and the builder who raised it came from the Roman world south of the Danube, and not from the native barbarian environment. The hypothetical reconstruction of the Germanic residence is a result of an intensive cooperation between the archaeologists who conducted the excavation and Studio 727 in Bratislava. The purpose of this contribution is to present the process of reconstruction with emphasis on the specifics of fourth-century wooden architecture. Plans were processed in AutoCAD, then 3D building models were modulated in Houdini. The resulting textured images were rendered in V-ray.

**Keywords:** *Roman period—wooden architecture—hypothetical reconstruction—Roman-Germanic relations*

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## Introduction

The archaeological excavation at Podunajské Biskupice was instigated by the planned construction of a bypass around Bratislava and its connection to the motorway. In the course of several months, archaeological companies investigated settlements which date back from the Stone Age to the High

Middle Ages. One of the most interesting discoveries was an inhumation cemetery dated to the period of the Avar Khaganate (Horňák, 2018, pp. 2–5).

From December 2017 to the end of April 2018, the remains of La Tène, late Roman and high medieval settlements were excavated in the part of the site that got the working title Podunajské Biskupice – Crossroads. The excavation was carried out by the archaeological private company VIA MAGNA Ltd. and the Department of Classical Archaeology of Trnava University in Trnava.

The first remains of sunken-featured structures were detected on the site as early as the beginning of December, when the archaeologists of VIA MAGNA Ltd. discovered the western edge of a large precinct. Due to unfavourable weather conditions and the size of the unearthed area, the work was suspended for three months. Meanwhile, the archaeologists reached an agreement with the construction company, which allowed them to investigate the entire area of the settlement including the parts situated beyond the planned road. Also Via Magna and the Department of Classical Archaeology agreed on cooperation, and the excavation was financed by both organisations (Hrnčiarik and Horňák, 2018, pp. 130–137).

The site Podunajské Biskupice – Crossroads is situated in the north-western corner of Žitný Ostrov, on the eastern outskirts of Bratislava (Fig. 1). Its historical development and the richness of settlement were affected not only by an excellent climate, but also by fertile land and sufficient humidity thanks to the nearby Danube. On the other hand, the river also caused floods and often changed its course throughout history, which meant that some of the excavated sites have been destroyed.

The size of the excavated area was around 48 × 58 m. Since the excavation took place in the early spring months, it was necessary to adjust the methodology to these conditions. On some of the surfaces, we had to stop working at a certain hour, and on others we could not start before a certain hour. This meant, paradoxically, that we were able to work on the site all day.

The archaeological excavation unearthed the remains of a Germanic residence, which formed part of a larger settlement. It was enclosed by a wooden fence that extended 40 cm below the point where it was recorded. The residence covered a rhombic area, with the north-eastern fence parallel to the south-western side. The north-eastern side of the fence diverted by about 80 degrees. The fence had probably enclosed the residence on all four sides, but only fragments of it were recorded in the southeast, east and northeast. In front of the northern, eastern and southern sides of the enclosure the authors detected a system of a large number of irregularly arranged pits of various sizes and depths. The pits were relatively shallow, around 15–20 cm from the point where they were recorded. Most of them did not interfere with one another – they formed three parallel rows – but some of them were in superposition. Since both the fence and the pits were rather shallowly sunken in the ground, the authors may assume that they served only to demarcate the area within the settlement, and were not the remains of a fortification system.

## Ancient residence at Podunajské Biskupice (Fig. 2)

The inner structure of the residence was formed by six rectangular buildings of wood, whose foundations survived in the form of trenches and postholes. Stone was used only to support the columns. These were arranged along the inner sides of the fence, with a courtyard in the middle. The superposition of buildings II and III, and V and VI, suggests at least two building phases of the residence.

The earlier building phase included buildings I, II and VI, while the second phase included buildings I, III, IV, V and VII. Since the fills of the trenches and postholes yielded minimal finds, an exact dating of the time frame between the two building phases cannot be provided. However, it should not be too broad, as the accompanying finds from the whole area of the settlement are homogeneous and date to a relatively short period at the end of the 4th century (Hrnčiarik and Horňák, 2018, pp. 130–137).

The residence can be dated by coin finds. The majority of them derive from a metal detecting survey conducted on the removed heaps of clay during the excavation. Although they mostly come from the layer above the residence, which means they cannot be associated with any settlement structure, their range gives us a clear idea of the time frame of the settlement. Only one coin was found in the trench filling of Building V. It is a small follis struck for Helena in Trier by emperors Constantine I (306–337) and Constantine II. (337–361), and is dated to the years 337–340 AD. The collection clearly suggests that most of the coins date to the second half of the 4th century AD. The latest of them belongs to Emperor Valens and dates to 364–367 AD.

## Roman-style residences in the territory of Slovakia

The architecture of the residence differs from standard Germanic settlements, which have buildings with halls or sunken-featured pit-houses (Varsik 2011, p. 45). The aristocratic residence in Podunajské Biskupice was built in wood, but its overall layout, the principles of symmetry and axiality predetermining the arrangement of the buildings, as well as the large square colonnade buildings, are architectural features and principles rooted in the tradition of ancient architecture. Both the architect, who designed the complex, and the builder who raised it seem to have come from the Roman world south of the Danube, and not from the native barbarian environment.

The phenomenon of Roman-style residences in the territory of Slovakia is known from the turn of the eras (Bratislava-Castle), throughout the Roman period (Bratislava-Dúbravka) to Late Antiquity (Milanovce-Veľký Kýr and in particular Cífer-Pác). The residences in Bratislava-Dúbravka, Veľký Kýr and Cífer-Pác were built in several phases. Their buildings from wooden or earth-and-timber phases bear resemblance to the buildings on the studied site (Hrnčiarik, 2013, pp. 209–216). Unlike the residence in Podunajské Biskupice, however, they were later rebuilt in stone. The Germanic residence in Podunajské Biskupice was inhabited only for a short period of time. Even though its structure resembles that of the residence in Cífer-Pác, it was not rebuilt in stone, and after a while was abandoned by its owner for unknown reasons.

**Building I** was situated in the south-eastern corner of the residence. It had a rectangular construction (outer dimensions 21 × 13.5 m), and the thickness of the foundation trench was in the range 24–47 cm. The perimeter construction was supported by three pillars of about 26 cm on three sides. A portico was situated along the entire perimeter of the building, and the load-bearing pillars in the corners were aligned with the perimeter walls of the main structure. The area between the portico and the main structure is about 130 cm. We assume that it is a residential building with a north-western entrance.

**Building II** consisted of an inner closed area surrounded by a foundation trench. The postholes were recorded also in the foundation trench of the building but did not protrude from its line. We did not record any traces of dividing walls inside the building. A portico was situated in the south. Dimensions with the portico: 7.5 × 6 m; enclosed area: 6 × 6 m.

**Building III** (Fig. 2) was the largest of the structures unearthed at Podunajské Biskupice. It consisted of an inner area, which was disturbed in the middle of the southern wall. The trench was completely destroyed in the north-east. The postholes were recorded also in the foundation trench of the building and they partly protruded from its line. The building was surrounded by a portico and was entered through it. From there one continued to a hall, and further on to two rooms of different sizes. The hall was closed in the north and open in the south. Dimensions with the portico: 26 × 15 m; enclosed area: 21 × 8 m. As for its function, a building of similar construction was unearthed on the site Oberleiserberg in Austria (Stuppner, 2008, pp. 284–285), where it was interpreted as a gate. In Podunajské Biskupice, however, such interpretation is impossible, since the part of the building, which, according to the Oberleiserberg model, should have an entrance, is closed and does not have the typical features of a gate construction. However, buildings similar to Oberleiserberg were excavated in Cífer-Pác. These were interpreted by T. Kolník and later by V. Varsik as dwellings or farm buildings (Varsik and Kolnik, 2016, pp. 257–268).

**Building IV** with inner dimensions 7.13 × 5.6 m was situated on the north-western side of the residence and was aligned with the perimeter fence. The mark after a horizontal foundation beam (38 cm thick) and the postholes (diameter 30–32 cm) suggest that it was a smaller building with a simpler construction than buildings I, III and V. A portico with pillars was situated on each of the four sides of the building. The dimensions of the outer construction including the portico were 12.8 × 13.3 m (Fig. 3).

**Building V** was situated on the south-western side of the residence and is similar to Building I in construction, just smaller. The rectangular structure with dimensions 7.6 × 8.9 m is surrounded by pillars on four sides and forms a 2.5 m wide portico. The outer dimensions are 9.2 × 15.8 m.

**Building VI** is in superposition with Building V, and the two buildings clearly could not have existed at the same time. It is a smaller rectangular structure (4.3 × 4.6 m) with an entrance hall built onto its northern side (depth 1.75 m). The door to the entrance hall can be identified on the northern, shorter side of the structure, and we placed a single wooden door here. The small dimensions of the building suggest that it was a farm building, which was later demolished and replaced with the larger Building V.

**Building VII** was situated in the north of the residence, and its foundations differed from those of the other buildings. They were formed by 9 postholes placed at regular intervals on an area of 3 × 3 m. The entire structure measured 4 × 6 m and probably served as a granary. Its floor was likely above the ground to protect it from moisture and rodents. The perimeter wall in the upper section consisted of plaited wickerwork, which ensured that air circulated in the room and the crops stayed dry. The load-bearing construction consisted of wooden beams. A granary is also assumed by V. Varsik in Cífer-Pác (Varsik and Kolnik, 2016, pp. 257–268). but there it was situated on the outer side of the residence. Behind Building VII was a pottery kiln. It was 4.24 m long and the inner width of the firing chamber was 0.58 m.

## Interpretation and hypothetical reconstruction

The hypothetical reconstruction of the Germanic residence is a result of an intensive cooperation between the archaeologists who conducted the excavation and an architect from STUDIO 727 in Bratislava. The authors will present the reconstruction process with emphasis on the specifics of fourth-century wooden architecture.

As the authors have already said, the only surviving parts of the residence in Podunajské Biskupice were the postholes and the foundation trenches. In the reconstruction, drew the authors on the knowledge of an analogous site in Cífer-Pác, which was investigated by Titus Kolník in 1969–1980 (Varsik, 2014, pp. 141). The three buildings there had similar ground plans as the structures in Podunajské Biskupice. They had a portico in front with a pillar on each side. The largest building had a portico only on the two longer sides of the building.

### Walls

In Podunajské Biskupice, the autors assume a structure of Fachwerk type, with vertical pillars mortised into a wooden horizontal construction. Between the pillars was plaited wickerwork, which was coated with clay plaster blended with chaff. Sometimes a thin wooden wall was used instead of wickerwork, and it was covered with reed, which is a good base material for clay plaster (Chybík, 2009, pp. 162).

Load-bearing constructions of wood and clay have a long tradition. The combination of these materials was frequently used in all ancient cultures, whether it was Ancient Egypt, Minoan Crete or Ancient Greece. Houses with wooden post-construction were built in in the territory of present-day Slovakia, Moravia and Bohemia as early as the La Tène period. In the 1st to 2nd centuries AD, earth-and-timber construction system was also used by Romans to build military camps. In this territory, such a camp is situated at Iža-Leányvár (Minaroviech, 2007, p. 95). The Romans continued to build these types of earth-and-timber structures in this region also in the late ancient period from the 1st to 4$^{th}$ centuries AD. Such structures have survived in the Roman civilian town at Carnuntum (Humer, 2009, p. 58). In his book *La Construction Romain* (Adam, 2005, pp. 104–105), J. P. Adam gives numerous examples of the use of woodworking joints in ancient Greece and Rome. One of them is the so-called Jupiter's joint, which derives from the shape of god Jupiter's lightning.

### Roof and roof covering

The authors assume that the material used for roof covering was reed, as there were no finds of ceramic roof tiles or nails (used on shingled roofs), and reed was likely available in the vicinity of the site. Roof pitch for this type of covering ranges from 42 to 45 degrees, in places with strong wind it is 50 degrees (Oláh et al., 2002). The right pitch and thickness (30–35 cm) ensures the durability of roof covering (50–100 years). A lower pitch is used on the parapets of gable roofs, but this means that rain water does not drain properly and may damage the roof. Therefore, roof covering should be changed more often on these portions of the roof than on others. Reed covering has various advantages, for instance it is a good thermal and acoustic insulator (Vlček, 2008, p. 43). A large number of natural sites rich in reed can be found in the south of Slovakia. Another analogy, that the authors used in the reconstruction were the buildings presented at the Freilichtmuseum Elsarn in Austria (www.freilichtmuseum-elsarn.at).

### Doors and windows

The exact locations of the building entrances have not been identified, but they are assumed on the longer sides of the structures towards the centre of the residence. The authors located them in places where the vertical wall construction is missing. They designed the entrance door from wooden boards on a wooden turntable. The windows were probably smaller to prevent heat leakage. Their position is only hypothetical. The window opening may have been covered with a wooden grille or animal skins. On the outside, the windows probably had wooden shutters for better insulation. Finer, glazed windows are not assumed in these buildings. In Roman military camps, window glass was used in the buildings of commanders and tribunes (Minaroviech, 2007, p. 99).

### Exterior of the buildings

We assume that the buildings were plastered with clay plaster of earthy colour. The main load-bearing constructions of wood were exposed. The buildings were surrounded with trenches, which drained rainwater from the roofs and prevented the buildings and pillars from soaking. However, these trenches were not recorded and are only assumed.

The postholes for the pillars supporting the portico are round and their cross-sections range from 37 cm (Building IV) to 90 cm (Building III). In comparison, the postholes in Cífer-Pác were square. Despite this difference we assume that on both sites the pillars were of circular diameter.

### Fence

The entire area of the residence was enclosed with a fence. The authors assume that in the first phase, the enclosure was formed of a wooden fence embedded into the ground, made of posts which carried horizontal wooden planks. In the second phase, the fence was extended to the east. In the west, the old fence was kept, but in the east it was rebuilt using a new technique. It was extended with posts that were irregularly sunken into the ground, and likely wrapped with wickerwork.

## 3D model of the residence (Fig. 3, 4)

The basic analytic tool used for the documentation of terrain indicators or archaeological features was photogrammetric documentation. This was done by a combination of vertical and oblique drone images from the height of about 20 m. The obtained photogrammetric model (produced in the AGISOFT software) was georeferenced into the coordinate system SJTS-SK. This allowed the authors to create precise DEM and comprehensive plans of the residence. The plans were processed in AutoCAD, and 3D building models were subsequently modulated in Houdini software. A simplified model was created, which was then approved by the authors of the excavation. After incorporating the authors’ comments, they clarified the constructional details of the building. When the model of the structure was approved, the authors conducted texture mapping. The authors looked for analogous examples of textures used on other archaeological structures. The textures were adjusted in the Photoshop programme, and then applied on the materials of the different parts of the model (wood, clay plaster and reed).

The surrounding terrain was modelled with the help of a model provided by archaeologists. The entire model was joined with the terrain to form a whole and was subsequently rendered in the

Redshift software. The rendered images were adjusted in Photoshop, and background was added. The most suitable images were selected for publication.

## Conclusion

The Germanic residence in Podunajské Biskupice is a good illustration of the spread of Roman inspired architecture to the Germanic environment. The reconstruction drew on authors' knowledge of the way wooden buildings were constructed in the Roman Empire, but also in Barbaricum. Ut was a unique architecture, one of the aims of the presented article was to approach the methodology of its reconstruction, which may help in similar constructions in the future. The practical knowledge of the architect in collaboration with an archaeologist was used to create the model. We clearly benefited from the fact that a similar, almost identical Germanic residence had been investigated in Cífer-Pác, not far from the studied site. The reconstruction of both sites was conducted by the co-author of this contribution, and the coordination of the work helped the authors complete missing information on each site. In this way, the author managed to provide a more reliable reconstruction of both residences. The researched objects are important in the development of architecture not only in Slovakia, but also in Europe. The 3D model created in this way made it possible to get a more realistic view of this unique Germanic residence. The model will be used in the monograph, which summarizes the results of archaeological excavation. At the same time, it will serve as a basis for the preparation of educational videos, which will be part of the upcoming exhibition on the Germanic nobility in Slovakia. The model will also be freely available on the website. Their visitor will not only be able to see the resistance virtually, but also to learn about the life of the Germans. The 3D model will be used, among other things, in the teaching process at secondary schools and universities with a focus on history and archaeology.

## Figures

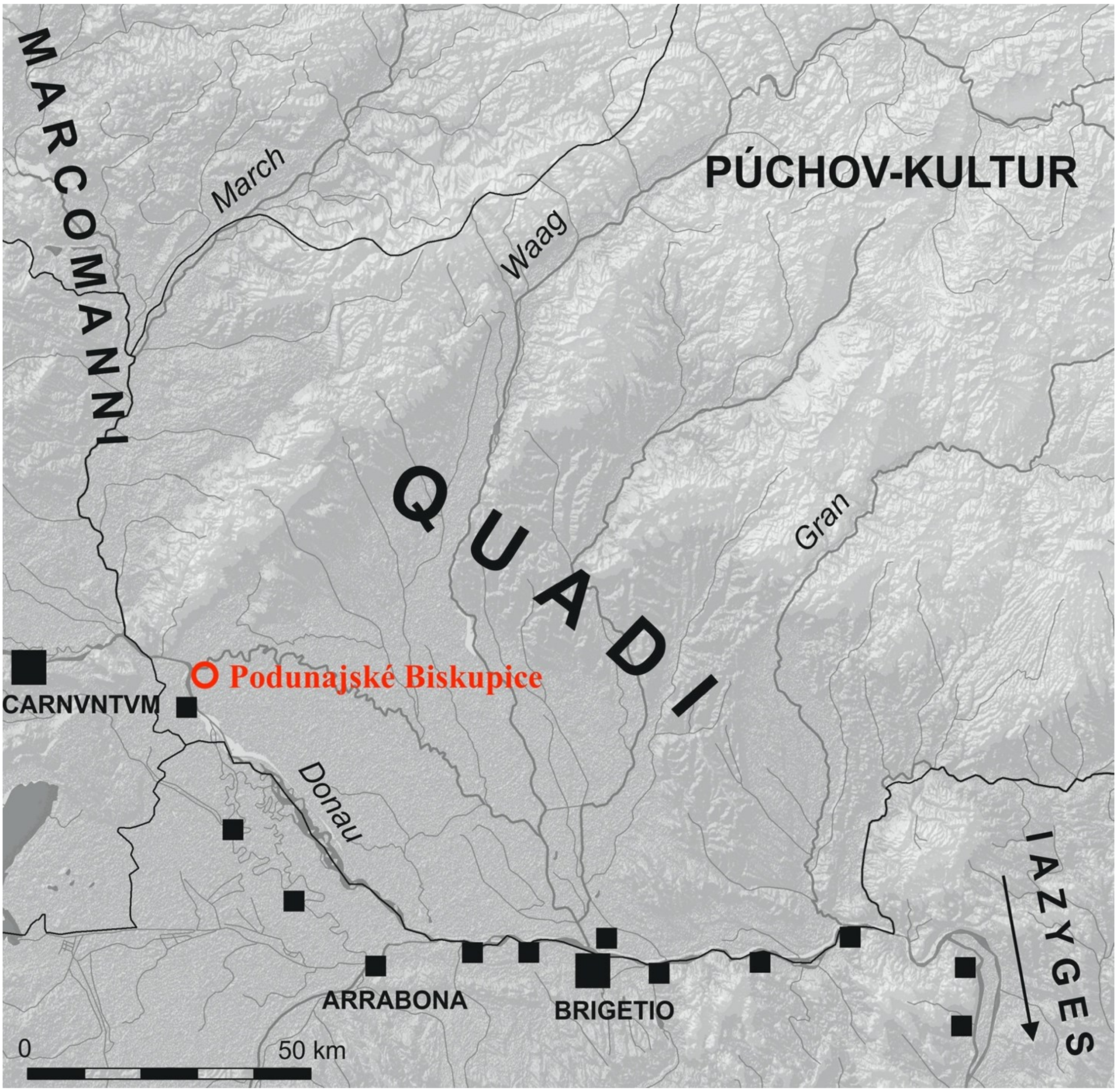


*Fig. 1. The Roman frontier in north Pannonia and Germanic residence at Podunajské Biskupice (© Hrnčiarik).*

*Fig. 2. Germanic residence at Podunajské Biskupice (© Horňák-Hrnčiarik).*

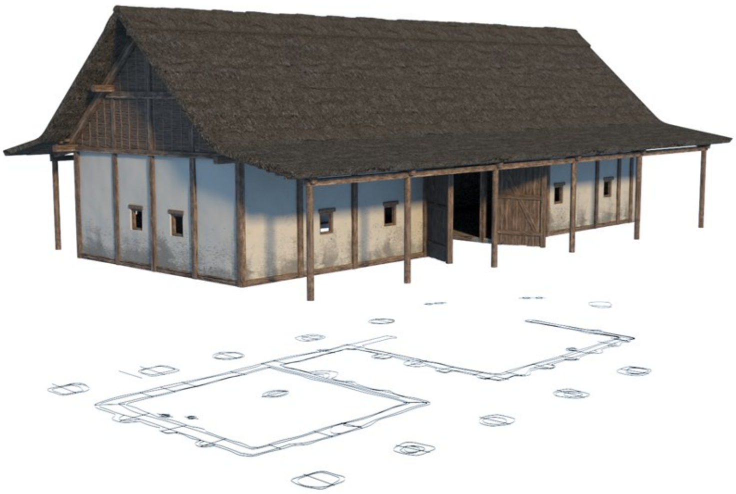

*Fig. 3. Ground plan of Building III (© Horňák-Hrnčiarik) and hypothetical reconstruction of the Building (© Horňák-Hrnčiarik-Minaroviech).*

*Fig. 4. Hypothetical reconstruction of the Building V (© Horňák-Hrnčiarik-Minaroviech).*

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# Session:
# Archaeological prospection by LIDAR beyond simple hillshading

**Irmela HERZOG | Michael DONEUS**

# Archaeological prospection by LIDAR beyond simple hillshading

Chairs:
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Michael DONEUS, University of Vienna, Austria

***Keywords**: Archaeological Prospection—Lidar—Digital Elevation Model*

For more than a decade, Lidar data has been used to detect and delimit archaeological sites by highlighting subtle altitude differences generated by the remains of these sites. In several European countries ordnance survey institutions nowadays provide Lidar data for archaeological purposes free of charge, and sometimes web map services are available that show hillshading views of this elevation data. Some researchers have pointed out the drawbacks of the ordnance survey Lidar data in their study area, favouring Lidar data acquisition commissioned by archaeologists. The latter procurement approach is the only option eligible in countries where official Lidar data is not accessible by archaeologists. In densely vegetated regions, filtering of the Lidar data is an issue. Additional issues include the accuracy of the measurements, irregular point density after filtering as well as combining data acquired in different campaigns or Lidar data with results of other prospection methods. Besides simple hillshading, several visualisation methods have been proposed that enhance detectability of specific archaeological features. Recently, pattern recognition and machine learning approaches have been used for the (semi-)automatic detection of sites in Lidar data, allowing to scan large regions with the aim of identifying sites of a predefined site type. The aim of this session was to show the potential of Lidar data beyond simple hillshading by papers focusing on:

- Best practice of Lidar data acquisition for archaeological purposes
- Data filtering in densely vegetated regions
- Comparison of Lidar with SfM approaches in areas with hardly any vegetation
- Potential and limits of different visualisation approaches
- Monitoring sites by comparing Lidar data acquired in different years
- Combining Lidar data with data derived from other prospection methods
- (Semi-)automatic detection of sites in Lidar data for instance by machine learning approaches.

# Testing ALS Visualisation Methods for Detecting Kiln Remains in a Densely Vegetated Area in Japan

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**Abstract:** In May 2018, Lidar data was acquired in a densely vegetated test area in southern Japan with the aim of detecting Sue kiln sites, that date back in the 9th century. In the region including the test area, several surveys as well as an excavation recorded evidence of such sites in recent years. As the densely forested, mountainous topography complicates any ground based archaeological investigations, airborne Lidar was considered the method of choice for surveying the area. This is the first study of this kind in Japan. The company that acquired the Lidar data also provided lists of ground points. Initial interpolations and visualisations relied on these lists; later the program SCOP++ was applied for generating digital terrain models based on alternative ground point selection strategies. The results of several approaches for visualising and analysing the Lidar data sets will be presented and discussed. For visualisations, mainly low-cost or free software was applied, including GIS software, the Relief Visualisation Toolbox (RVT), and planlauf/TERRAIN for 3D virtual flights. Additional GIS approaches for analysing the data are presented: (1) contour maps that assist navigation in the field, (2) a density map of ground points allows assessing the reliability of the Lidar visualisations, (3) cross sections are useful for validating the features recognized and measuring their depth or height, and (4) slope maps support delimiting manmade terraces, identifying platforms and are an important input for deductive predictive modelling of Sue kiln sites. The work of mapping probable kiln locations detected in the LiDAR data and verifying these sites by traditional prospection methods is still in progress. Only after reliably identifying a large number of Sue kilns in the test area, approaches such as predictive modelling or machine learning may be applied for locating additional kilns in this region.

***Keywords:*** *ALS—ground point filtering—Lidar visualisation—point density map—slope map—Sue kilns—Japan*

**CHNT Reference:** Herzog, Irmela; Doneus, Michael; Shinoto, Maria; Haijima, Hideyuki, and Nakamura, Naoko. 2021. Testing ALS Visualisation Methods for Detecting Kiln Remains in a Densely Vegetated Area in Japan. Börner, Wolfgang; Kral-Börner, Christina, and Rohland, Hendrik (eds.), Monumental Computations: Digital Archaeology of Large Urban and Underground Infrastructures. Proceedings of the 24th International Conference on Cultural Heritage and New Technologies, held in Vienna, Austria, November 2019. Heidelberg: Propylaeum.
doi: 10.11588/propylaeum.747.

## Introduction

At Nakadake Sanroku, Kagoshima prefecture, southern Japan, remains of Sue pottery kilns dating in the 9th century were first detected in the 1980ies (Fig. 1a). Kiln site clusters for the production of

Sue ware exist all over Japan, Nakadake being the southernmost location. Since 2012, field walking surveys and geophysical prospection as well as an excavation have documented several Sue pottery kilns in the Nakadake region (Nakamura and Yoshimoto, 2015; Nakamura and Shinoto, 2015; Matsusaki, 2018; Shinoto and Nakamura, 2016). These investigations resulted in an estimated number of about 60 kilns in this region, an unexpectedly large number in this remote region.

The Sue kilns were constructed by digging tunnels into the slope of hills. In the Nakadake area, excavation results suggest an approximate tunnel length of 8 m and a width of about 2 m. The maximum height of the vessels found in such tunnels is about 50 cm, thus providing a lower limit for the tunnel height. At the foot of the tunnel, ash heaps contain waste from the firing process. It seems that most of the tunnels collapsed in the course of time resulting in elongated shallow depressions. These remains are hard to detect due to their mostly inconspicuous shape and because of their location in a densely forested, mountainous area (Fig. 1b). Only if the ash heaps were partly destroyed by erosion processes and relocated downhill by heavy rains, the kiln locations could be identified successfully by walking the area. Consequently, the efficiency of traditional methods for identifying kiln locations is rather limited.


*a* *b*

*Fig. 1. a) Location of the study area; b) typical vegetation (© Google Earth; Maria Shinoto).*

In this situation, airborne Lidar was considered the method of choice for effectively identifying additional kiln sites. In Japanese archaeology, previous Lidar projects are limited in number and focussed on the measurement of prominent features such as tombs or castle remains (e.g. Akashi, 2010; Fujii et al., 2015); explicit experiments with different filters and visualisations were not included. This new project had to face complex challenges in view of mostly inconspicuous sites in an area that experienced considerable relief change by agricultural use during medieval and early modern times. Further complications are introduced by dense vegetation, steep slopes, and large differences in altitude ranging from 20 to 265 m above sea level in an area of about 0.5 km². In May 2018, Lidar data was acquired using a scanner of type RIEGL VUX-1 UAV on an octocopter (Glyphon Dynamics GD-X8-SP) in a test region covering 0.5 km² (Fig. 2). At least 100 points/m² were recorded with a conservatively estimated horizontal precision of 10 cm on densely covered forest surface.

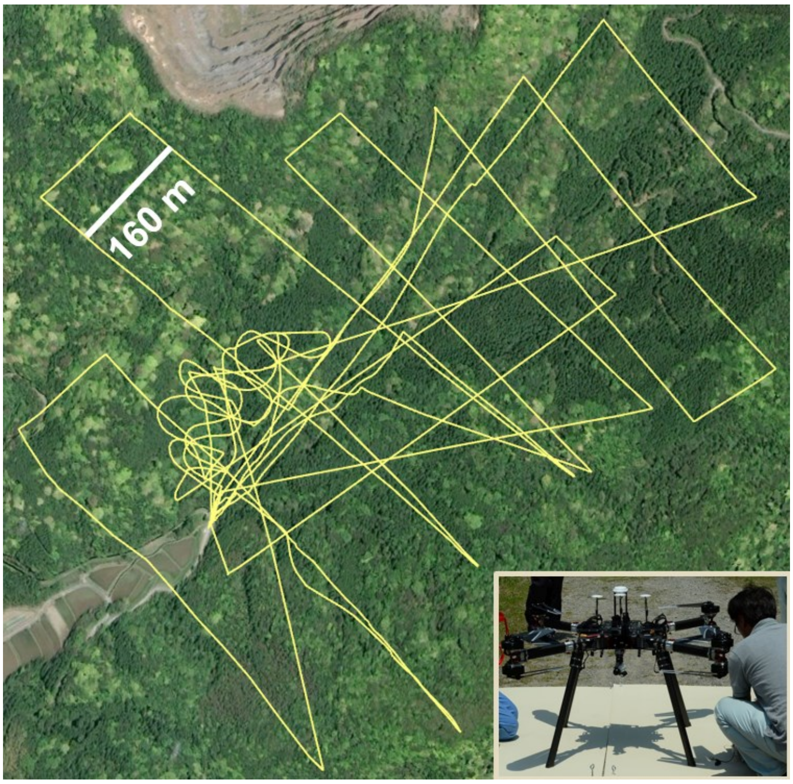


*Fig. 2. Itinerary of the UAV flights (yellow) including flights for calibration purposes. Inset image: preparing the UAV (© Google Earth; Maria Shinoto).*

Experience from the Rhineland area had shown that sunken roads could be reliably identified in forest areas based on 1 m grid data (Herzog, 2017). Therefore, it seemed more than likely that the laser scanning elevation data of the Japanese study area suffices for detecting kiln sites. However, postprocessing the data turned out to be a challenge. This article will discuss the outcomes including some of the difficulties met when applying the low-cost or free software available for the visualisation of Lidar data. The results of analysing the data by additional GIS approaches are presented: these include contour maps, that assist navigation in the field; a density map of ground points for assessing the reliability of the Lidar visualisations; cross sections, that are useful for validating the features recognized and assessing their depth or height; slope maps, that are an important input for deductive predictive modelling of Sue kiln sites.

## Processing the Lidar data

In May 2018, Nakanihon Air Service (NNK) recorded the Lidar data and about one month later, they provided the outcome in four file formats, subdivided into nine tiles, each covering 400 m×300 m (Fig. 3). The file formats and their respective sizes are: LAS (29.4 GB), XYZ (163 MB), GRD (10.7 GB), and TIF (1.2 GB).

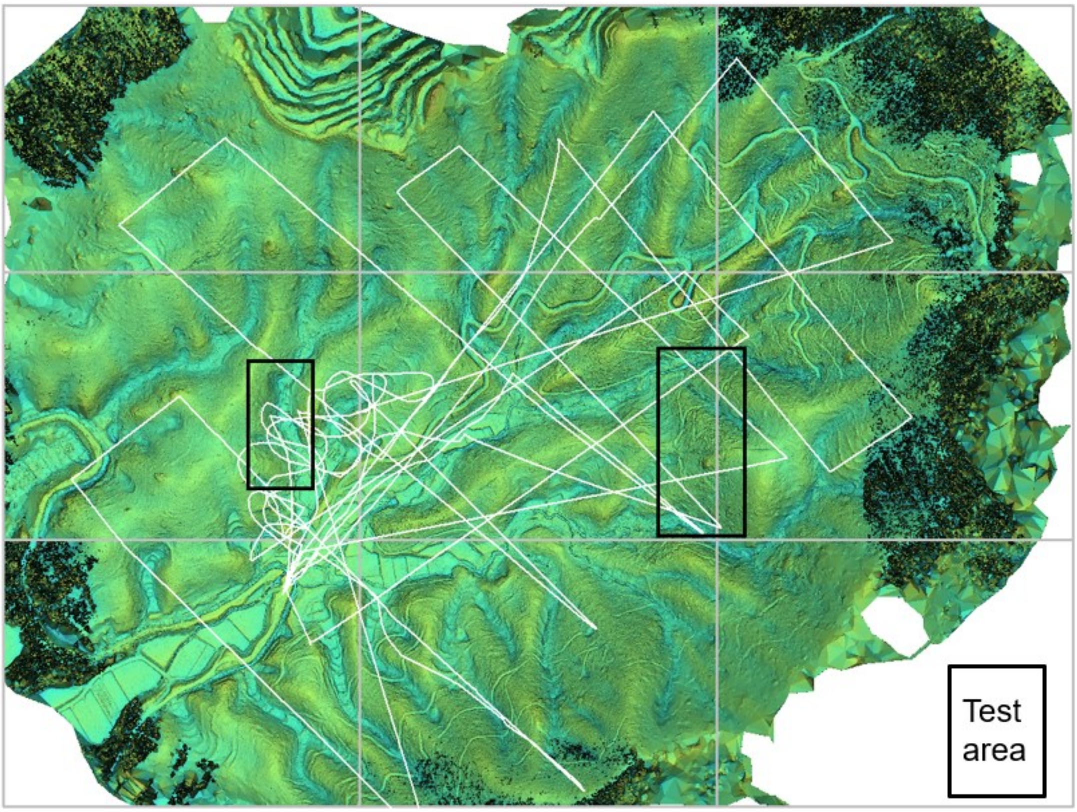


*Fig. 3. Visualisation of the Lidar data created by NNK divided into 9 tiles (tile size: 400 m×300 m), UAV itineraries, and test areas (© Nakanihon Air Service; Irmela Herzog).*

The LAS file format is an open standard maintained by the American Society for Photogrammetry and Remote Sensing (https://www.asprs.org/divisions-committees/lidar-division/laser-las-file-format-exchange-activities). The binary LAS files contain the 3-dimensional point cloud data recorded during the UAV flights. Each XYZ file is an ASCII list of irregularly distributed 3D points. These points are the results of a filtering process intended to remove all non-ground points from the point cloud. The GRD files are in the Golden Software ASCII Grid file format and store raster data with a cell size of 5 cm. The raster grids were computed by interpolating the XYZ points.

The TIF files present an impressive visualisation in areas covered well by the UAV itineraries (Fig. 3). However, it is difficult to delimit the areas of high reliability. Another issue is the fact that many viewers of these visualisations tend to misinterpret the relief, i.e. the valleys are seen as ridges and vice versa. Moreover, the TIF files do not allow further analysis such as slope calculations or cross sections.

Initially, generating visualisations based on the high resolution ASCII grid files seemed to be the most efficient approach. QGIS was used for converting the GRD files from Golden Software ASCII Grid to ESRI ASCII grid. The latter file format is supported by most GIS software as well as the Relief Visualisation Toolbox (RVT – Kokalj et al., 2013; Kokalj and Somrak, 2019) and the Windows program planlauf/TERRAIN (planlauf GmbH, 2019). Several additional grids were interpolated based on the XYZ data by MapInfo with plugin Vertical Mapper (MIP/VM). The grid with a resolution of 10 cm created by triangulation interpolation will be used for the comparisons presented in the next section.

The software package SCOP++ (Doneus and Briese, 2006; Pfeifer et al., 2001) was applied for processing the LAS files, providing alternative ground point filter results and subsequent interpolations. Due to substantial variations in vegetation density, SCOP++ was run with two different filter strategies:

Strategy 1: Filter settings tweaked for high detail, DTM resolution: 7 cm

While the results are very good in areas with a fairly low vegetation density, in areas with extremely dense vegetation, a considerable number of non-ground points is still clearly visible and this complicates the detection of archaeological features.

Strategy 2: Filter settings adapted to very dense vegetation, DTM resolution: 20 cm

The results of this strategy appear more smooth, and terrain details at a small scale are obscured.

Details on such filter strategies are published in Doneus et al. (2020).

Two test areas were selected for analysing and visualising the Lidar data (Fig. 3). They differ in that the task of analysing test area no. 1 in the western part of the survey area was considered comparatively easy, whereas test area 2 is more of a challenge. Test area 1 is entirely contained in one tile, whereas the data of test area no. 2 was supplied in two different tiles. Most of test area 2 is in higher altitudes than test area 1, and the expectation is that Sue kiln sites are mostly located in low lying parts of this landscape.

## Visualisation of the Lidar data

MIP/VM offers routines for creating shaded relief visualisations for DTMs. Identical hill-shading parameters were applied for the MIP/VM interpolated 10 cm grid and the two SCOP++ grids. This allows comparing the outcomes of the different interpolation and filter approaches. Figs. 4 and 5 also show the initial TIF images provided by NNK. The visualisations of test area 1 in Fig. 4 depict a valley with several incised features, some of which seem to overlap.

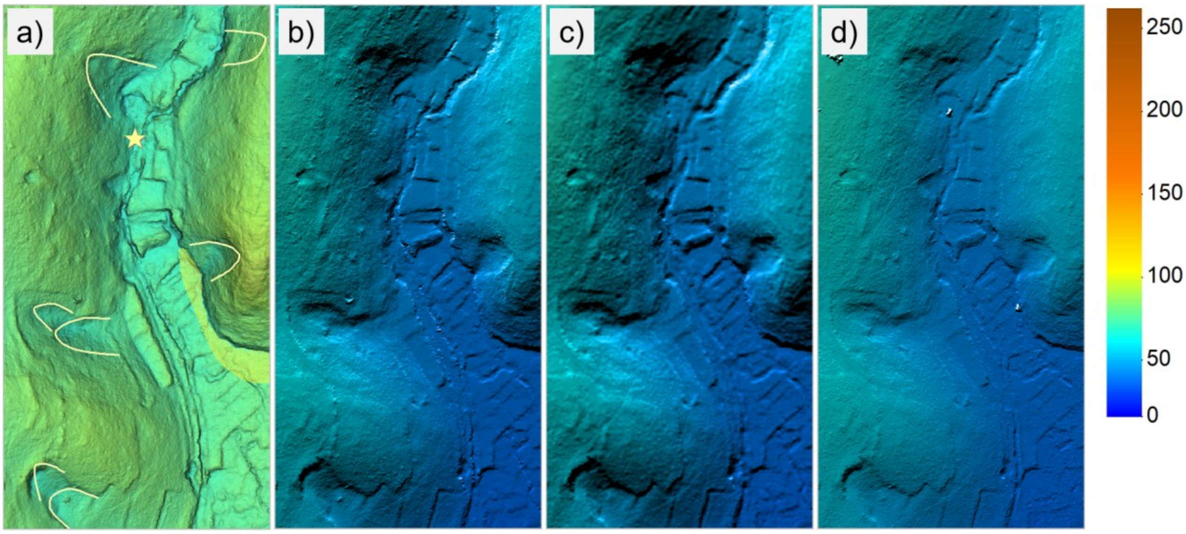


*Fig. 4. Visualisation of the Lidar data in test area 1: a) created by NNK, yellow lines delimit potential kilns, find locations are also marked in yellow, b) to d) hill-shading (azimuth=0, inclination=30, contrast=150, brightness=80) created by MIP/VM using the colour profile shown on the right, b) XYZ point interpolation by MIP/VM, c) SCOP++, strategy 2, d) SCOP++ strategy 1 (© NNK, Irmela Herzog, Michael Doneus, and Maria Shinoto).*

These typical depressions (delimited by yellow lines in Fig. 4a) were also documented in other valleys where indicators of kilns were found, these indicators include sherds from ash heaps and readings from geomagnetic surveys (Shinoto, 2019a). Although the valley depicted in Fig. 4 had been covered by walking several times since 2012, no kilns were detected before the Lidar data was acquired. Using a map generated from the Lidar data, typical Sue pottery sherd was found in a creek (marked by a yellow star symbol in Fig. 4a), providing evidence that at least one of the kiln site candidates in the upper valley is indeed a kiln site. In the eastern part of the valley depicted in Fig. 4a, the area with the yellow pattern includes find spots of several fragments originating from an ash heap in the incipient stage of erosion, discovered when revisiting the valley.

The legend of Fig. 4 also applies for the test area 2 visualisations b) to d) in Fig. 5. Terraces and paths are clearly visible in all shaded relief images of the DTMs shown in Fig. 5. In the south of test area 2, a valley and some depressions on the slope towards the valley can be detected. At first, one of them was considered as a possible kiln location, but this turned out to be highly unlikely (see below). The depressions were probably created by erosion processes.

Figs. 4 and 5 b) to d) illustrate the differences in the filtering strategies. Fig. 5b) suggests that the DTM derived from the XYZ points includes undergrowth points in densely vegetated areas because the surface is very uneven in some parts that appear fairly smooth in the SCOP++-DTMs. On the other hand, in the XYZ-DTM, no gross errors are evident in the test areas, but both SCOP++ filter results show small spikes indicating non-ground points. In the southern part of Fig. 5, the XYZ-DTM has gaps due to lack of point data, whereas the SCOP++ results show clusters of spikes in these areas.

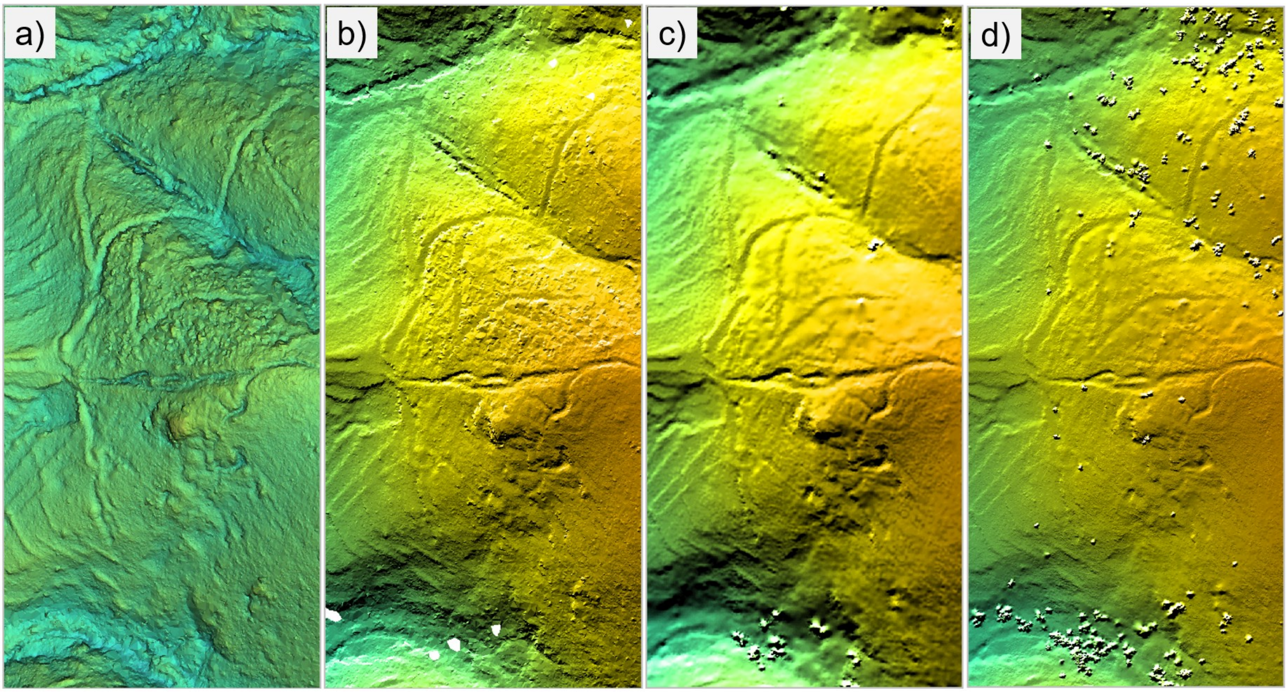


*Fig. 5. Visualisation of the Lidar data in test area 2: a), b), c), d) as in Fig. 4 (© NNK, Irmela Herzog, and Michael Doneus).*

In the archaeological community additional visualisations of the ALS data are often considered in order to avoid some of the drawbacks of simple hill-shading. A popular alternative visualisation method is Simple Local Relief Model (SLRM) also known as trend removal. The aim of this approach is to remove the large-scale landscape trend from the DTM so that only local small-scale features remain (Hesse, 2010).

Often, GIS software is able to generate SLRM visualisations. The SLRM computations in Fig. 6 were created by the applying the *Mean(neighbourhod)* and the *Minus Calculus* tool provided by the Sextante toolbox in gvSIG. A neighbourhood radius of 20 pixels was chosen, corresponding to 2 m. For the resulting local relief DTM, an intuitive colour scheme (local depressions are displayed in green and minor earth deposits such as mounds or local ridges are shown in brown) is combined with some hill-shading to enhance readability. This visualisation is very useful for identifying extremely shallow relief features and delimiting features such as platforms, sunken roads, and rice terraces. SLRM avoids the risk of optical illusions inherent in shaded relief images, thus supporting a more accurate mapping of archaeological features in GIS. But some drawbacks are known as well: for larger features local relief elevations are underestimated, features on gradients appear somewhat distorted (Hesse, 2010), and SLRM often produces images showing fake ditches for mounds (Hesse, 2016).

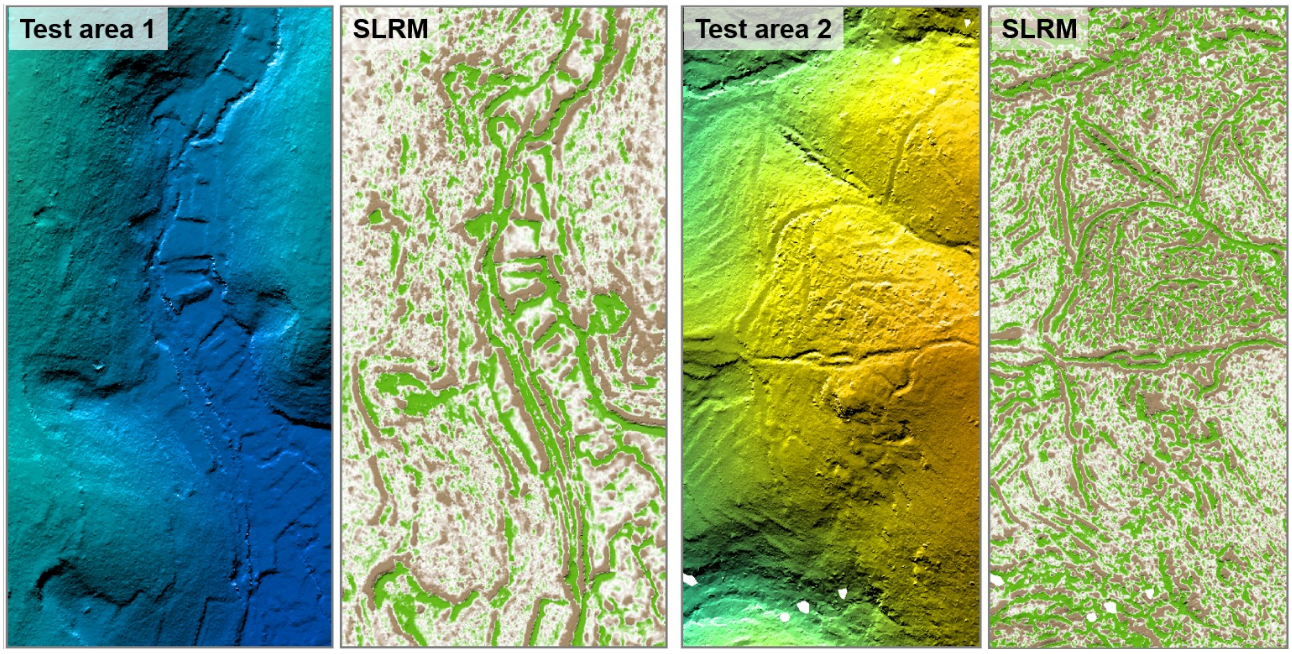


*Fig. 6. Hill-shading of test areas 1 and 2 as in Fig. 4b) and 5b) and corresponding SLRM visualisations (© Irmela Herzog).*

The user-friendly toolbox RVT offers nine additional methods for visualising elevation grid data beyond simple hill-shading images and SLRM. All desired visualisations can be generated in one run. Version 1.3 of this software was successfully applied for nearly all Lidar grid tiles provided by the Ordnance Survey institution in the Rhineland (Herzog, 2017). For the Rhineland data, hill-shading from multiple directions as well as positive and negative openness were considered the most useful RVT methods. For five of the Lidar data grid tiles in the Japanese study area, all possible visualisation options of RVT 1.3 with default parameters were generated for unchanged elevation and exaggeration factor 5. A selection of the resulting images is presented in Fig. 7. Multiple hill-shade images are the favourite visualisations of many archaeologists, because they deliver an intuitive picture avoiding the drawbacks of single hill-shade images. But directional bias results in horizontal displacement of features. Therefore, this visualisation is often supplemented by another visualisation such as positive or negative openness. For the two test areas, principal components analysis and anisotropic sky-view-factor provided useful visualisations.

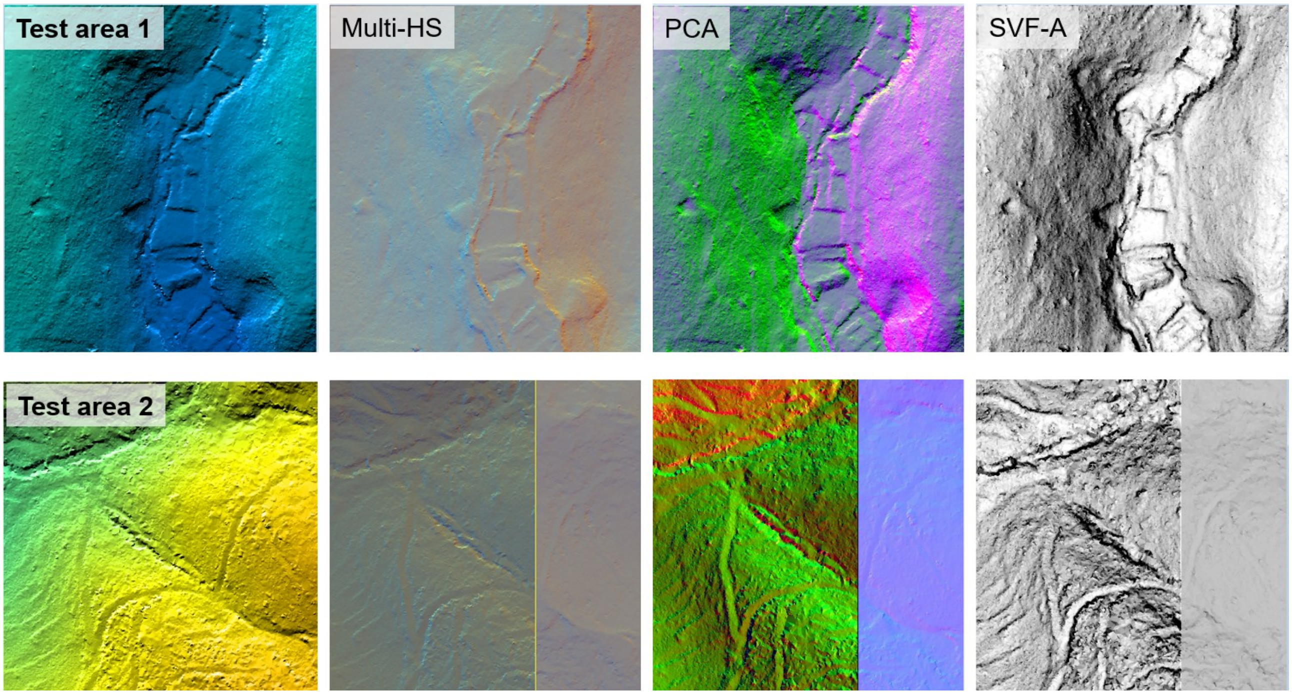


*Fig. 7. Hill-shading of the northern parts of test areas 1 and 2 as in Fig. 4b) and 5b) and RVT results (Multi-HS = multi hill-shading; PCA = principal components analysis; SVF-A = anisotropic sky view factor) based on the GRD tiles (© Irmela Herzog).*

However, two difficulties were met when working with the RVT toolbox and the tiled data: some of the RVT outcomes based on ESRI ASCII grids derived from the GRD files supplied by NNK or calculated by GIS software were disappointing at first sight. Only after appropriate adjustment of the colour scheme, local features became visible. This issue could be avoided to some extent by converting the DTMs to the GeoTiff file format by QGIS 3.4. Another issue is evident in Fig. 7, which is based on GeoTiff files derived from the GRD files: the results for each tile file depend on the mean local standard deviation of the altitudes. The tile covering the eastern part of test area 2 includes many spiky areas in the east (cf. Fig. 3), therefore mean local variation is high, and the contrast of the visualisation in the western part of the tile is very low.

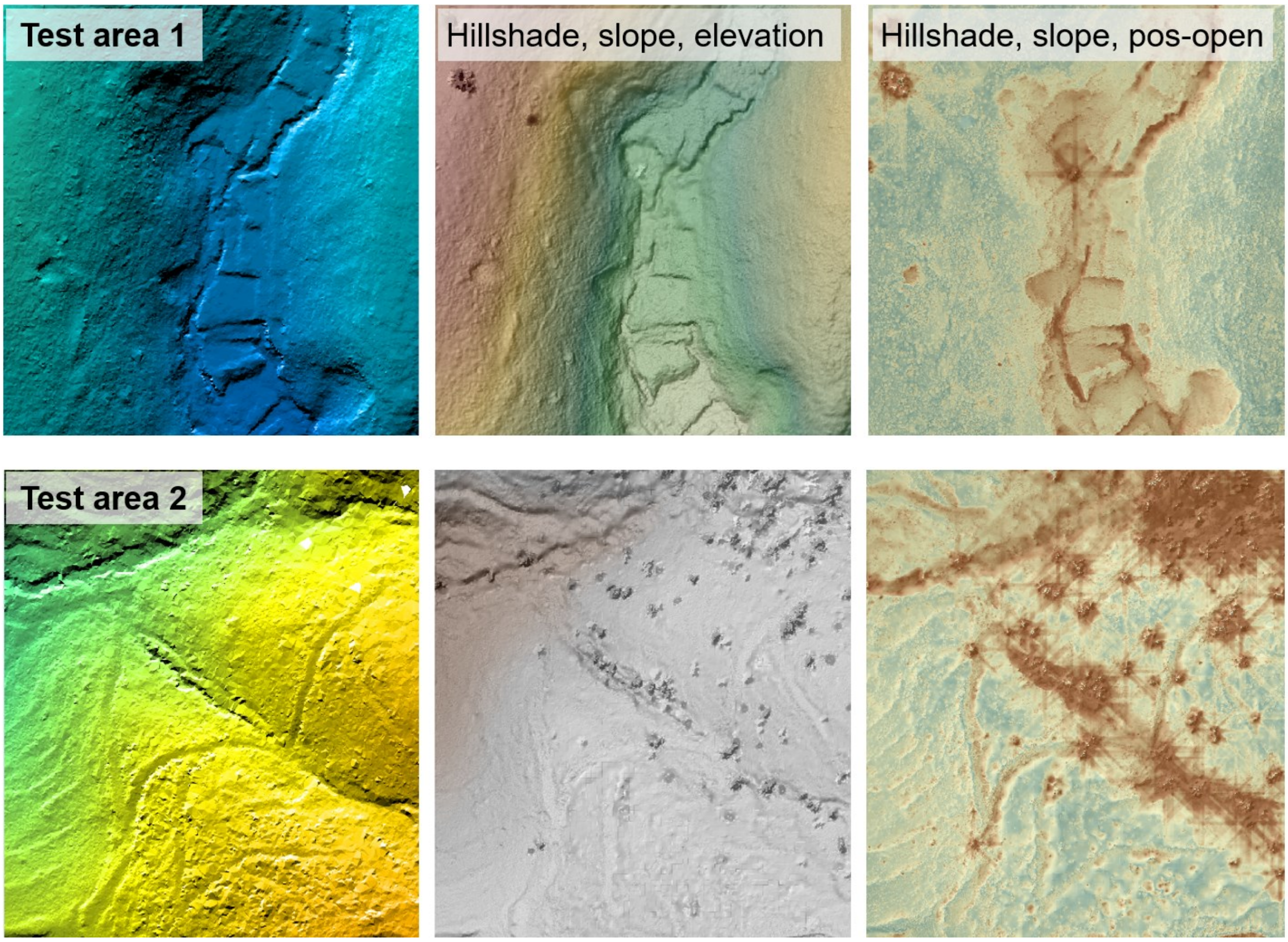


*Fig. 8. Left: Hill-shading of the northern parts of test areas 1 and 2 as in Fig. 4b) and 5b). Centre and right: results of blending several visualisations (© Michael Doneus, Irmela Herzog).*

The visualisations of the SCOP++ outcome (strategy 1) in Fig. 8 use GIS functions to blend several layers, thus combining a set of visualisations into a single image (see also Kokalj and Somrak, 2019). In the images in the centre, slope, shaded relief and colour-coded heights (focusing on the range between 30 and 140 m above sea level) were combined. The images on the right were generated from shaded relief, slope and positive-openness layers. Considering test area 1, the combined visualisation depicted in the centre of Fig. 8 turned out to be particularly helpful for the archaeologists because some of the details of the probable kiln sites are clearly visible. But in test area 2 with higher elevations, this visualisation lacks contrast. So even with very refined blended images, it might still be necessary to check several visualisation methods or to adjust their parameters in order to unleash the full potential of the Lidar data for detecting archaeological features. In this project, the comparison of several visualisations was also an integral part of preparations for field work targeted at checking possible sites.

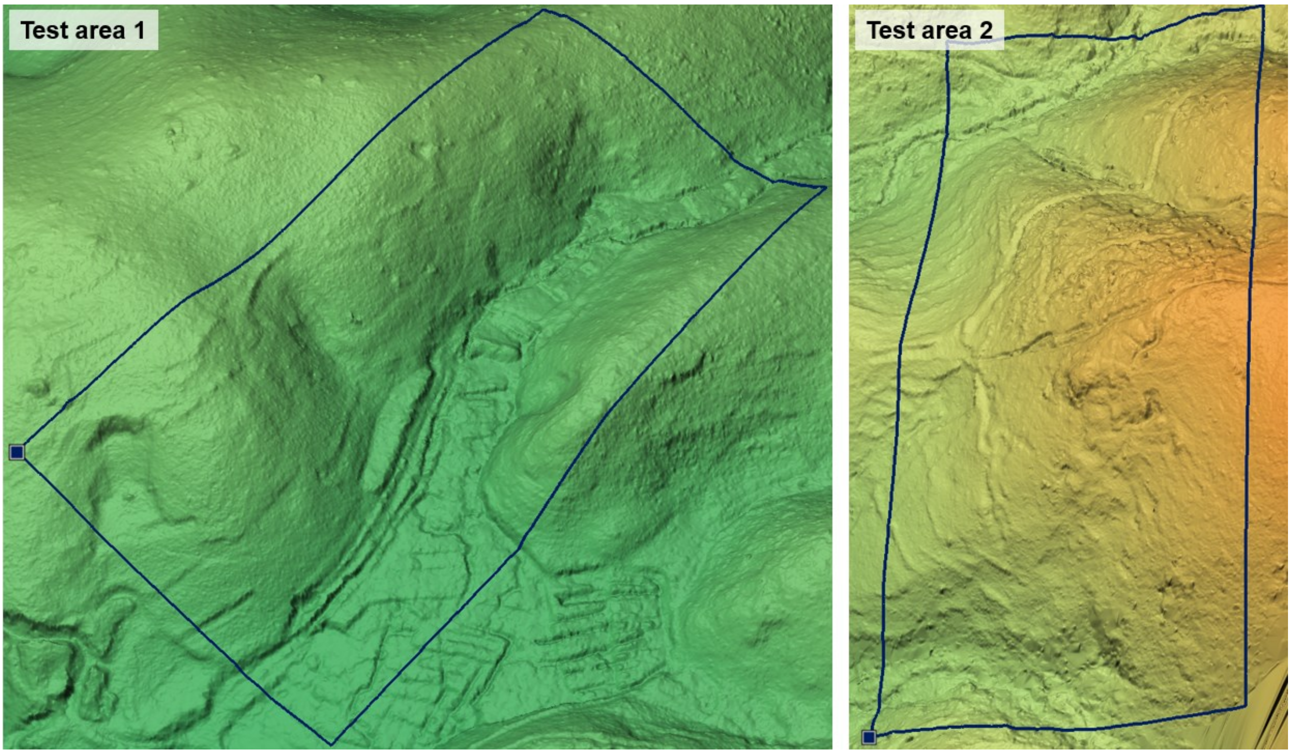


*Fig. 9. 3D views generated by planlauf/TERRAIN based on the XYZ-DTM (© Irmela Herzog).*

An alternative low-cost program (non-commercial licence) for DTM visualisations is planlauf/TERRAIN (planlauf GmbH, 2019). This Windows application uses gaming approaches for mesh decimation and thus allows virtual flights through the 3D landscape in real time that can be saved as mpeg files. The 3D environment provides a very intuitive approach for assessing the shape of a feature, thus supporting the decision if a feature is manmade (see also Verhoeven, 2017). The program includes many additional functions such as the import of shape files, marking features detected in the DTM by pins and exporting these pin locations in a CSV file. In Fig. 9, the outlines of the test areas were imported and high-resolution screenshots saved to file. It took some time to learn how to successfully invoke the functions listed above, but there are many more, which might prove useful. For instance, the two dimensional top views of the terrain may be exported in GeoTiff format for further processing in a GIS.

## Analysis beyond visualisation

A cross-sectional view of the DTM allows checking if the structures identified in a visualisation are relevant or mere optical illusions. Based on such views, measuring the depth of depressions and the height of earth deposits is easy. Fig. 10 shows three cross sections for both SCOP++ DTMs. The locations of the vertical cut planes are indicated by the arrows in the maps. The cross section for the probable kiln location in the northeast of test area 1 clearly shows the differences between the two SCOP++ DTMs: the strategy 2 DTM is more smoothed, whereas more pronounced features but also spikes are visible in the strategy 1 DTM cross sections. Detecting such a depression with a depth of only about 35 cm but a width of 10 m in densely vegetated areas by walking is not possible. The depression in the east of test area 1 is more pronounced (about 2 m), and only minor differences between the two strategies are visible along this line (second cross section in Fig. 10). At the bottom of Fig. 10, a cross section of a feature in the south of test area 2 is shown. The hill-shading visualisations suggested some similarity with a kiln-shaped depression, but the cross-section reveals that the shape is different.

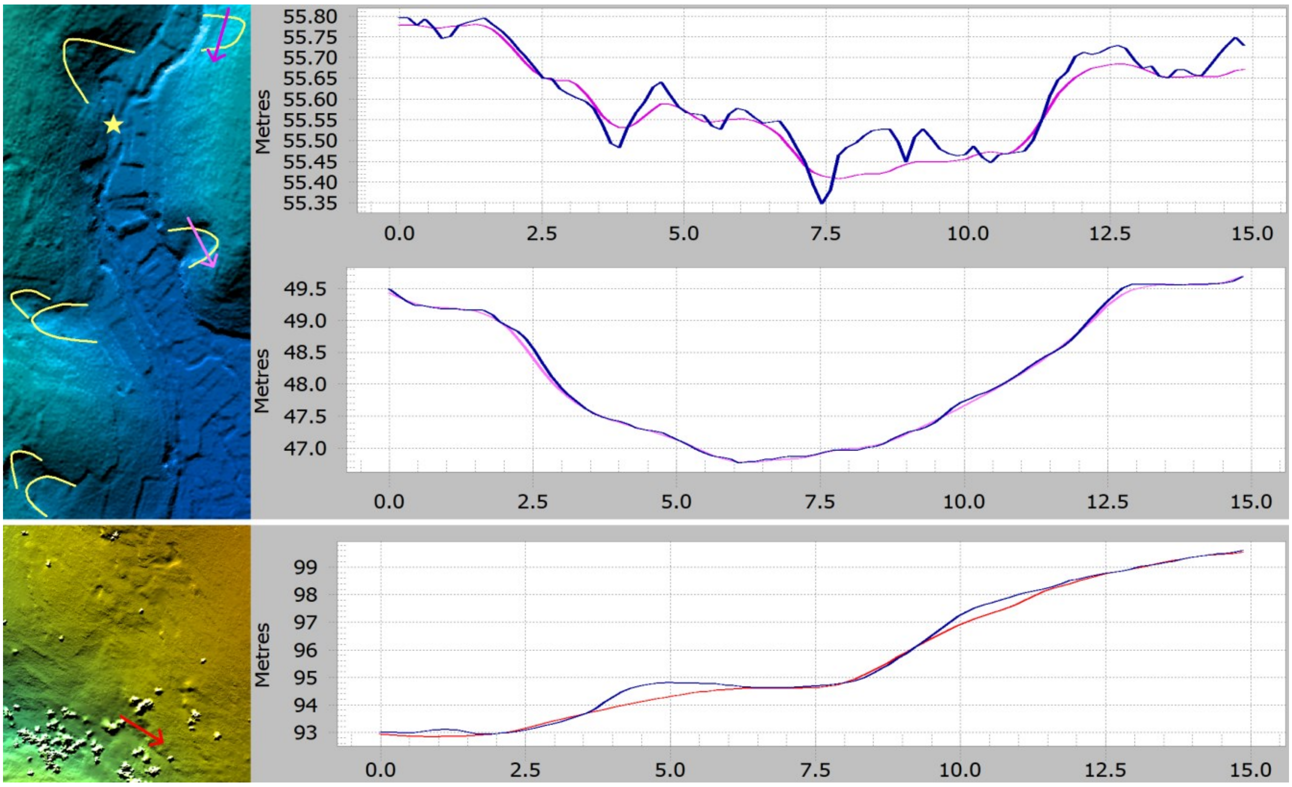


*Fig. 10. Three cross sections (see maps on the left) of the SCOP++ DTMs: blue – strategy 1; violet/red – strategy 2 (© Irmela Herzog).*

Most GIS software packages include a procedure for generating contour lines from a DTM. The archaeologists checking the kiln site candidates in the field reported that contour line maps (with labels) assist orientation in case of GPS inaccuracies. Contour lines were created with elevation intervals of 20 and 50 cm (Fig. 11 left: 50 cm).

Slope maps support delimiting manmade terraces, identifying platforms, and nearly level paths along a contour line (Doneus and Briese, 2006). The slope maps shown in Fig. 11 (centre and right) were generated by MIP/VM. Different methods for deriving slope from a DTM grid are implemented in GIS software, therefore the results might differ (de Smith et al., 2007, pp. 259–261). Future research with the aim of predictive modelling of Sue kiln sites will also apply slope maps: currently, it is assumed that the kilns are located on slopes ranging from 28 to 45 %. For this reason, this slope range is highlighted in yellow in Fig. 11 (centre and right). The probable kiln in the east of test area 1 (cf. Fig. 4a) is mostly steeper than this slope range, and this is one of the reasons why further investigations in the field are required. Moreover, slope maps also assist in identifying isolated misclassified points that appear as spikes in the DTM. The slope map typically displays very steep slopes in a small zone centred on these points (e.g. Fig. 11 right, southern part).

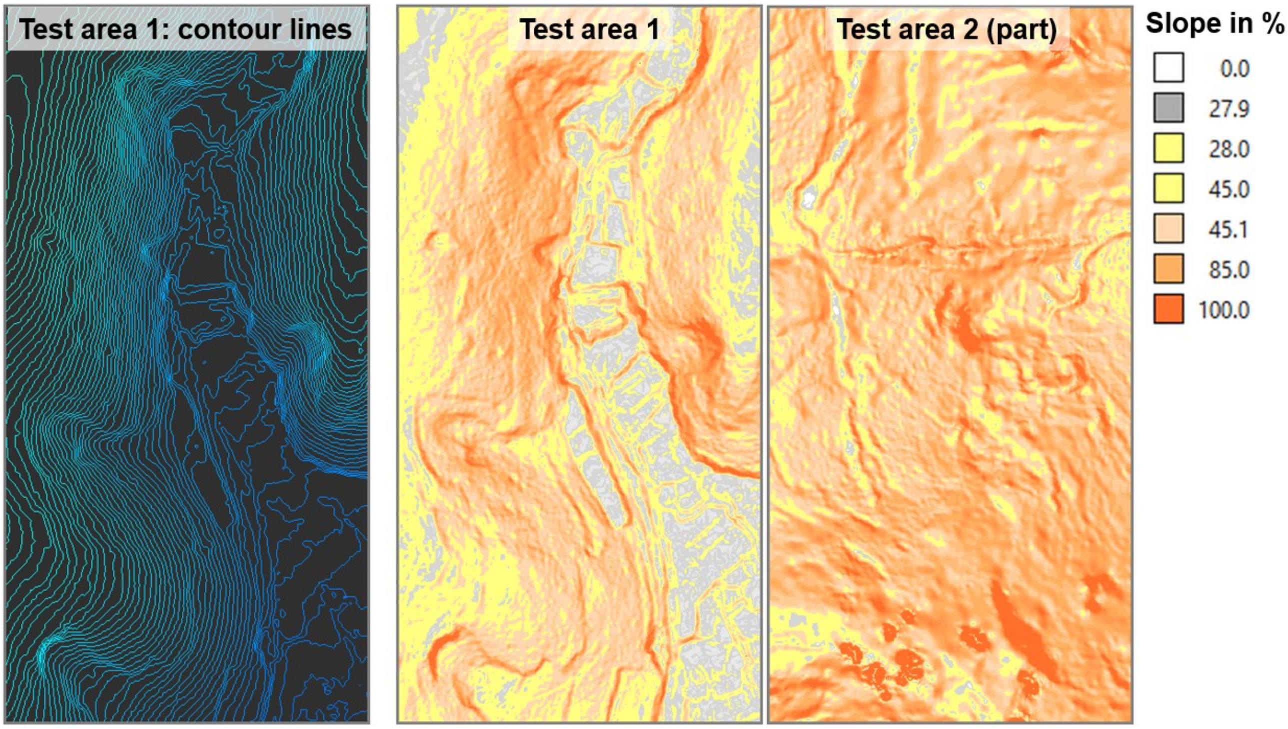


*Fig. 11. Results of GIS methods: contour lines and slope maps (© Irmela Herzog).*

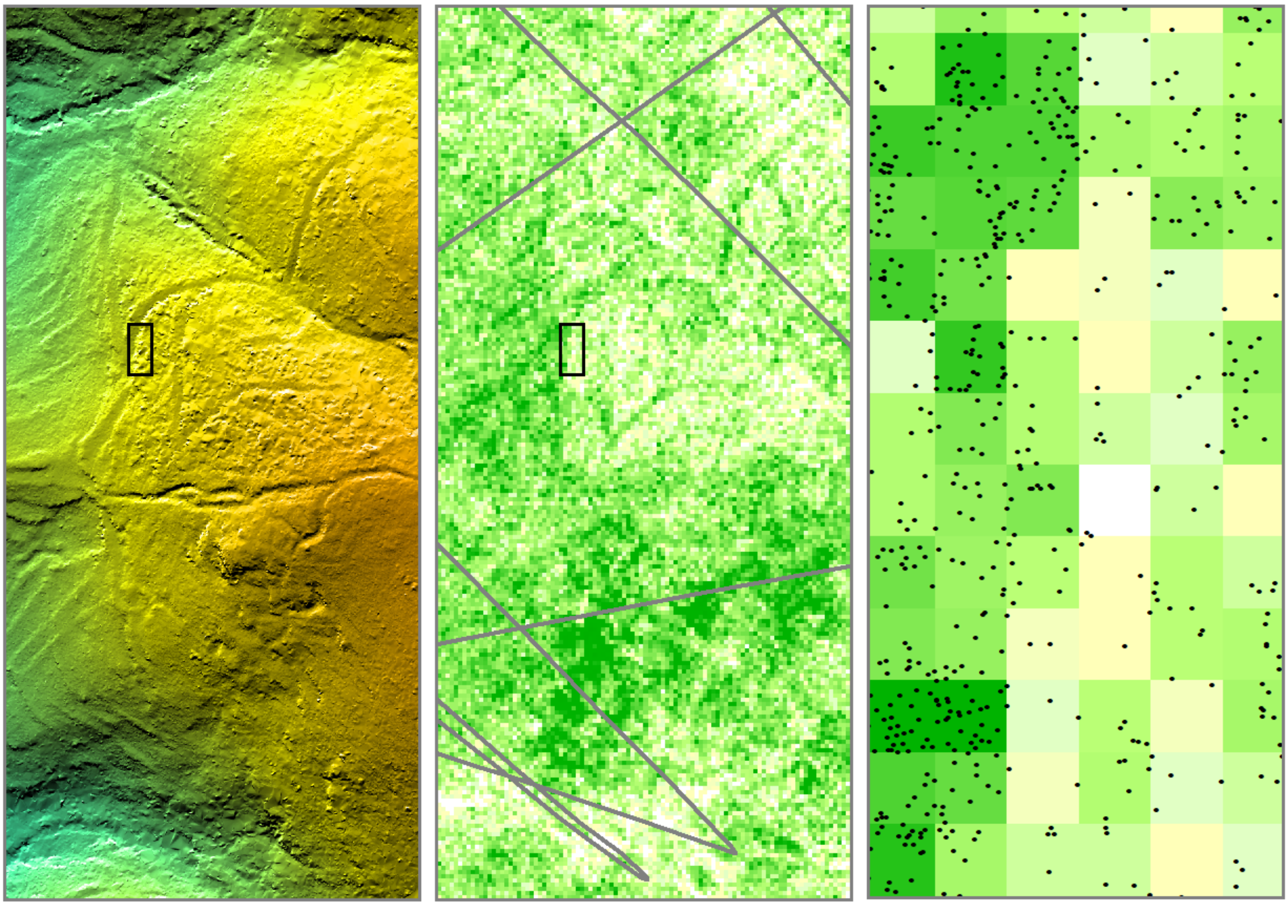

*Fig. 12. Test area 2. Centre: Density map of the number of ground points in the XYZ files. Pixel size: 1 m². Right: Enlargement of the area delimited by the black rectangle in the left and the centre image (© Irmela Herzog).*

Simple approaches for assessing the reliability include a density map of the recorded surface points. Kernel density estimation with a bounded radial-symmetric Epanechnikov kernel (radius 1 m) was applied for generating a density map with a cell size of 1 m based on the XYZ points (de Smith et al., 2007, pp. 128–133). Fig. 12 illustrates the considerable variation in ground point density, showing the selected ground points in the image on the right. Although at least 100 points/m² were recorded, the filtering process sometimes selected only one of these points.

The DTM grid resolution does not necessarily correspond to the point density. According to the *Nyquist Limit*, also known as *Shannon's Sampling Theorem* (Beex, 2004), at least 1 point/m² must be present for reliable identification of an approximately rectangular archaeological feature with a minimum edge length of 2 m or more, i.e., the probable dimensions of the Sue kiln remains to be detected. So for instance in several patches located in the southern part of test area 2, it might not be possible to detect typical kiln sites reliably based on the XYZ data, even in the absence of ground point misclassifications. This area is well covered by UAV itineraries (grey lines in Fig. 12, centre). In some other parts of the survey area, the ground point density and the distance to the next UAV itinerary seems to be related. This observation, too, needs further investigation.

## Discussion and conclusions

In the densely vegetated test region in south Japan with substantial variation of altitudes, UAV-based Lidar proved to be a viable survey method. Currently, reliability of ALS data in such complex situations is still an issue. Nevertheless, the two filter approaches presented—one of them tweaked for high detail, the other one minimising misclassifications of non-ground points in very densely vegetated areas—provide the basis for a large set of useful visualisations allowing to detect possible Sue kiln locations.

Free or low-cost software supports the creation of a large number of (archaeologically) useful visualisations. In this case study, SLRM, shaded relief from multiple directions and a combination of hillshade, slope and colour-coded heights seemed to be most helpful. Virtual cross sections are useful for validating the features recognized and assessing their depth or height. Validation should also include inspection of the ground point density in the areas considered. Slope maps allow delimiting former rice terraces, identifying platforms, and contour line paths.

In early spring 2019, field work aimed at checking 12 selected probable kiln sites identified in Lidar visualisations ruled out two of these locations, archaeological evidence for the existence of kilns in the other places was recorded (Shinoto et al., 2019a; 2019b). Supplemental magnetometer investigations at these locations are planned in near future. Orientation during ground inspection was assisted by SLRM maps and simple labelled contour maps (interval: 20 cm) in case of GPS inaccuracies. Additional ground-based archaeological investigations are planned for winter 2020/2021 with the aim of checking those probable kiln locations identified in the Lidar data that were not visited in spring 2019.

Unfortunately, the range of shapes of such kiln remains as well as their location parameters is not yet known for sure. Only after reliably identifying a large number of kiln sites, dependable predictive modelling and machine learning algorithms for detecting these archaeological features automatically in ALS data can be developed.

## Acknowledgements

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# Semi Supervised Learning for Archaeological Object Detection in Digital Terrain Models

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**Abstract:** The use of deep learning techniques for detection of objects in imagery has spread to many disciplines, including archaeology. Deep learning models are exploited in detection of objects and structures in archaeology using natural and satellite images, as well as aerial and terrestrial laser scanning data. A well-known limitation of such models, specifically deep supervised models, is that they highly depend on large volumes of labelled data. For tasks with a small amount of labelled data and a huge amount of unlabelled data, unsupervised pretraining or transfer learning can be used. In this work, a product of airborne laser scanning data, i.e., Digital Terrain Models (DTM) is used to detect structures such as bomb craters, charcoal kilns, and barrows in the Harz region of Lower Saxony, Germany. Labels for only a small area are available while the majority of the region is unlabelled. Therefore, the large number of unlabelled examples are used to pretrain an auto-encoder model in an unsupervised fashion, and then a supervised training is performed using the labelled data. This combination of unsupervised learning and supervised learning is hereafter referred to as Semi Supervised Learning (SSL). Experiments in this study show that SSL helps gain up to 9 % improvement in performance compared to using supervised training alone.

***Keywords:*** *Archaeology—Object Detection—Semi Supervised Learning—LiDAR—Digital Terrain Model*

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## Introduction

Cultural heritage preservation is crucial for appreciating past human accomplishments and learning from their actions. A step towards this goal is the identification and registration of archaeological monuments. While archaeologists are able to detect archaeological sites in the field and document them, different measures have been undertaken to improve the process leading to more efficient documentation of interesting archaeological landscape structures and monuments. One effective method is using LiDAR data or one of its derivatives, such as DTMs. Archaeologists use these data to manually identify, label, and keep records of interesting monuments and structures. In an attempt to automate the process, Meyer et al. (2019) used LiDAR data and the eCognition tool by Trimble

(2014) to detect monuments such as ridge and furrow areas, burial mounds, and Motte-and-Baily castles. To automate the process even further, labelled DTM data can be used by different techniques in artificial intelligence, specifically deep learning, to train a model that learns to distinguish different objects. The trained models can then detect similar objects and label them in regions not inspected manually. In the next step, the proposed structures can be checked directly in the field.

Deep learning models can learn to classify, i.e., produce a label or category for a given segment of the DTM. It can also learn to categorize each point in the given DTM to a specified class. The former technique is referred to as classification while the latter is called semantic segmentation. Additionally, another technique called instance segmentation takes an input and gives as output a bounding box, semantic segmentation mask, and a class label for each instance in the input. While all of the three techniques have proved to be effective, they highly depend on a large volume of labelled data to learn recognizing objects. In this work, a large volume of unlabelled DTM data is leveraged by an unsupervised pretraining technique followed by a supervised training with a small amount of labelled data to detect archaeological objects. The focus of this research is the detection of bomb craters, charcoal kilns, and barrows in the Harz mining region of Lower Saxony, Germany. This region has been shaped by mining for thousands of years, which is represented by a huge amount of archaeological sites (Malek, 2019). It is also home to the UNESCO world heritage site, “Historic Town of Goslar, Mines of Rammelsberg, and the Upper Harz Water Management System” (Bergwerk Rammelsberg Altstadt Goslar Oberharzer Wasserwirtschaft, Goslar: Stadt Goslar, 2017). For the experiments presented in this paper, three types of structures, as previously mentioned, are chosen which are not only typical but also occur in large numbers. The rest of the paper is organized to include the proposed method and related works, experiments and results followed by a conclusion and hints towards future research directions.

## Proposed Method

Previous works show successful applications of deep learning techniques using laser scanning data. Politz et al. (2018) use deep classification models to detect road segments and water bodies. Trier et al. (2019) detect archaeological structures such as kilns, mounds, cairns, and cattle feed stance, among others. Kazimi et al. (2018) use deep classifiers to detect streams, lakes, and road segments. Kazimi et al. (2019a) apply semantic segmentation on DTM data to identify man-made landscape structures. Finally, instance segmentation technique is used by Kazimi et al. (2019b) to retrieve pixel-wise labels as well as boundary lines for archaeological objects.

Methods explained above are examples of supervised learning where corresponding labels are present for each example. In our study, DTM data for Lower Saxony is available with labels for only a small portion of the region. Therefore, we make use of the unlabelled data by pretraining an auto-encoder model and then use the pretrained model for semantic segmentation with the labelled data. An auto-encoder model is a model that learns abstract representations of high dimensional inputs, encodes them to a compressed, low dimensional vector which is then used to reconstruct the original input. The advantage of such models is that the compressed encodings can be used for other learning tasks or visualization purposes. Maschi et al. (2011) used stacked convolutional auto-encoders for extracting features from images and using the features for object and digit recognition tasks.

Socher et al. (2011) used recursive auto-encoders for predicting sentiment distributions in textual data. Zhou and Paffenroth (2017) used auto-encoders for anomaly detection in data. In this study, we train an auto-encoder for feature extraction in DTM data. We then use the extracted features for semantic segmentation and producing pixel-level class labels for a given DTM input. The model used for auto-encoding and semantic segmentation in this research is the well-known architecture called Deeplab v3+ proposed by Chen et al. (2018). It is illustrated in Fig. 1.

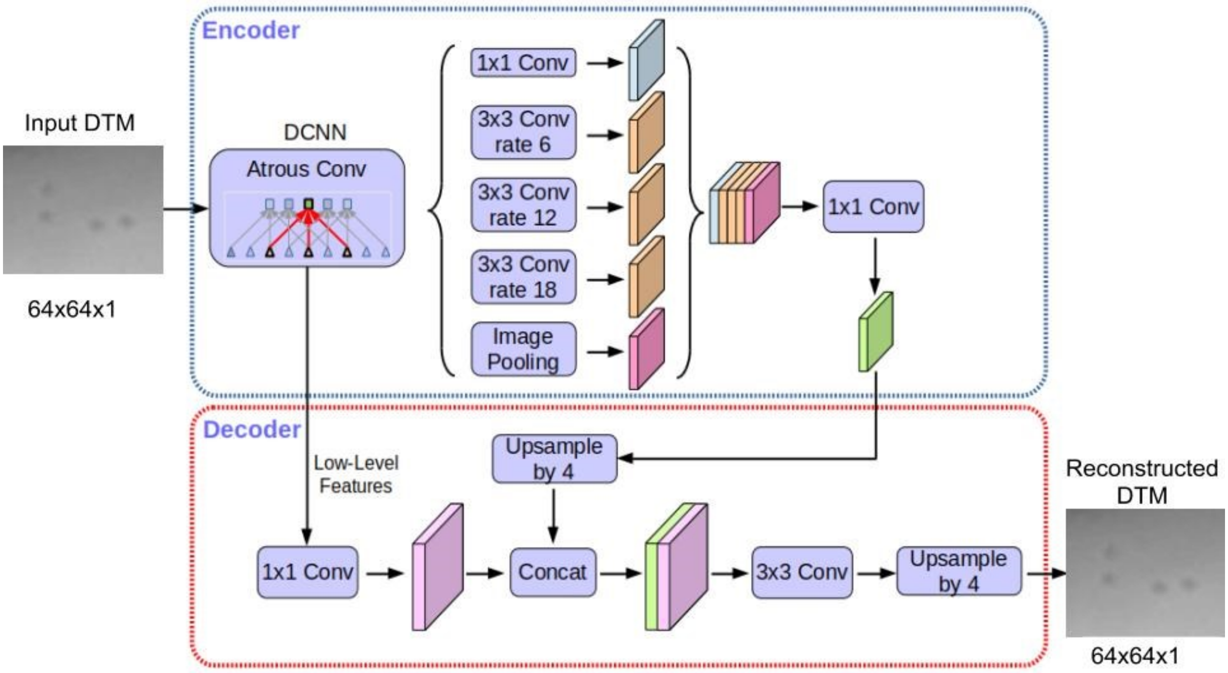


*Fig. 1. The architecture of the model. It is first used as an auto-encoder with the unlabelled data. Then, the number of filters in the last convolutional layer is changed to match the number of object categories, and it is trained further with labelled data in order to perform semantic segmentation and produce labels for each pixel in the input DTM.*

Deeplab v3+ is originally used for semantic segmentation in natural images, and it follows an encoder-decoder approach. The encoder extracts low-dimensional compressed features from images using combinations of multiple deep convolutional layers and spatial pyramid pooling (He et al., 2015). The features are then fed to the decoder which learns pixel-wise label maps for the given input by a few layers of bilinear upsampling and convolution, in addition to making use of low-level features extracted from the earlier layers of the feature extraction network.

The encoder-decoder-like architecture of Deeplab v3+ makes it suitable for us to use it in both stages of our approach, namely unsupervised pretraining with unlabelled data, and supervised semantic segmentation with limited labelled data. In the pretraining stage, the model is trained to learn a compressed representation of given DTM examples using the encoder and reconstruct the original DTM from the features using the decoder. Hence, the number of input channels and output channels in the network is the same (i.e., 1), and the model is optimized to minimize the mean squared error function. In the second stage, the learned encoder parameters are fixed, but the decoder is trained to use the extracted features by the encoder and generate segmentation maps for the given DTM. Therefore, the number of output channels depends on the number of categories or labels in the task at hand. In our study, we investigate 3 types of structures: bomb craters, charcoal kilns, and barrows, but we have an additional category for background pixels, leading to a total of 4 categories.

To evaluate the approach, in addition to running experiments on the unlabelled and labelled data with the proposed method, we also conducted experiments using the pure semantic segmentation approach trained only on the labelled data with randomly initialized parameters. The results of the experiments are given in the following sections in detail.

## Experiments

Experiments are performed using the proposed workflow with DTM data for Lower Saxony. Details of the dataset and experiment set-ups for the SSL and pure supervised step are given in the following sections.

### Dataset

The data used in this study is DTM data with a resolution of half a meter per pixel acquired from Lower Saxony, Germany. The DTM has a resolution of half a meter per pixel and covers an area of approximately 47000 square kilometres. Areas in the Harz mountains are labelled to indicate structures such as bomb craters, charcoal kilns and barrows. Statistics for labelled examples are shown in Table 1.

| Category | Examples | Minimum Diameter | Average Diameter | Maximum Diameter |
|---|---|---|---|---|
| Bomb Craters | 1135 | 2.5 meters | 6 meters | 10 meters |
| Charcoal Kilns | 1044 | 4 meters | 11.5 meters | 19 meters |
| Barrows | 1322 | 4 meters | 17 meters | 32 meters |

*Table. 1. Statistics for labelled examples.*

For training the auto-encoder in the first step, random patches of size 64 × 64 pixels are extracted from the unlabelled regions. In the second step, i.e., in supervised training with labelled data, patches of 64 × 64 pixels are extracted such that they contain either a whole object (one of bomb craters, charcoal kilns, or barrows) or at least a quarter of the object. The data is divided into 80 %, 10 %, and 10 % split for training, validation, and testing.

### Training Set-up

In this experiment, Python and Keras (Chollet, 2015) library are used for training and evaluation. Both models, auto-encoding and semantic segmentation are trained for 100 epochs each with input sizes of 64 × 64 pixels, Adam optimization with default arguments, and batch sizes of 32. The objective and metric function for the auto-encoder is mean squared error. The objective function for semantic segmentation model is categorical cross entropy, and the metric function is Intersection over Union (IoU).

## Evaluation and Results

The SSL and Pure Supervised Learning (PSL) methods are both compared using the standard evaluation metrics for semantic segmentation, namely Intersection over Union (IoU). IoU, also referred to as Jaccard index, is defined as the percentage of overlap between true labels and those predicted by the deep learning models. It is a ratio of the number of common pixels between the true label map and the predicted label map as shown in Equation 1. The values range from 0 (bad) to 100 (good) showing the percentage of overlap.

$$IoU = \frac{True\ Labels \cap Predicted\ Labels}{True\ Labels \cup Predicted\ Labels} * 100 \quad (Eq. 1)$$

The semantic segmentation model in the PSL, and the second stage of the SSL are both trained, validated, and tested on the exact same set of examples. During training, the parameters leading to the best IoU values for the validation data are saved to disk and used after training for evaluating the prediction results on the test data.

IoU results for SSL and PSL evaluated on the test set are shown in Table 2. Since the majority of the pixels in the given DTM patches are background pixels, the mean IoU could be quite deceptive. A model could produce a background label for all the pixels in an input and could still get a mean IoU of above 50 percent. Therefore, in addition to the mean IoU, we list individual IoU results for each class for better verification. It is clear from the IoU results that SSL improves detection performance in general, and more specifically for small structures like charcoal kilns.

| Method | Mean IoU | IoU bomb craters | IoU charcoal kilns | IoU Barrows |
|---|---|---|---|---|
| **PSL** | 67.8 | **85.8** | 15.5 | 71.4 |
| **SSL** | **76.8** | 85.2 | **48.0** | **75.1** |

*Table 2. IoU on test set.*

Qualitative evaluation results for both methods are illustrated in Fig. 2. Label maps predicted by SSL are smoother and more accurate while those by the PSL are sparse and less accurate, as seen in Fig. 2, especially in the second row. SSL predictions are more compact and a higher number of instances are captured, while predictions by the PSL are generally sparse and the number of undetected examples is higher.

## Conclusions

In this research, the effect of semi-supervised learning is studied on the detection of archaeological objects in airborne laser scanning data. The method used is auto-encoder pretraining, followed by supervised fine-tuning. The architecture experimented with is the well-known Deeplab v3+ architecture which, due to its encoder-decoder property, is suitable to be used in both stages of the experiments, namely pretraining and fine-tuning. To evaluate the effect of such an approach in detecting patterns in DTM data, a parallel experiment is conducted using solely the supervised approach, and the results are compared. As observed in the IoU values in Table 2, and qualitative results in Fig. 2, semi-supervised learning improves IoU up to 9 percent. The results are especially significant for small structures like charcoal kilns.

Even though the IoU results prove that leveraging unlabelled data and applying semi-supervised learning techniques help to get better predictions, there is more room for improvement. First of all, the labelled examples are not perfectly created. Knowing the location and average diameter of the known structures, for simplicity, a distance buffer has been used to create circular polygons in ArcGIS marking instances of mentioned categories. The buffering method introduces a lot of false labels, i.e., many background pixels are labelled as one of the classes and for bigger instances of the structures, some pixels are falsely labelled as background. Additionally, the completeness of the ground truth labels plays a role in the performance of the neural networks. Some instances in the training region that are not easily visible to the human eye have not been labelled, which could cause confusions to the model during training. Correcting the labelling problems will contribute to an increase in prediction accuracy of the models.

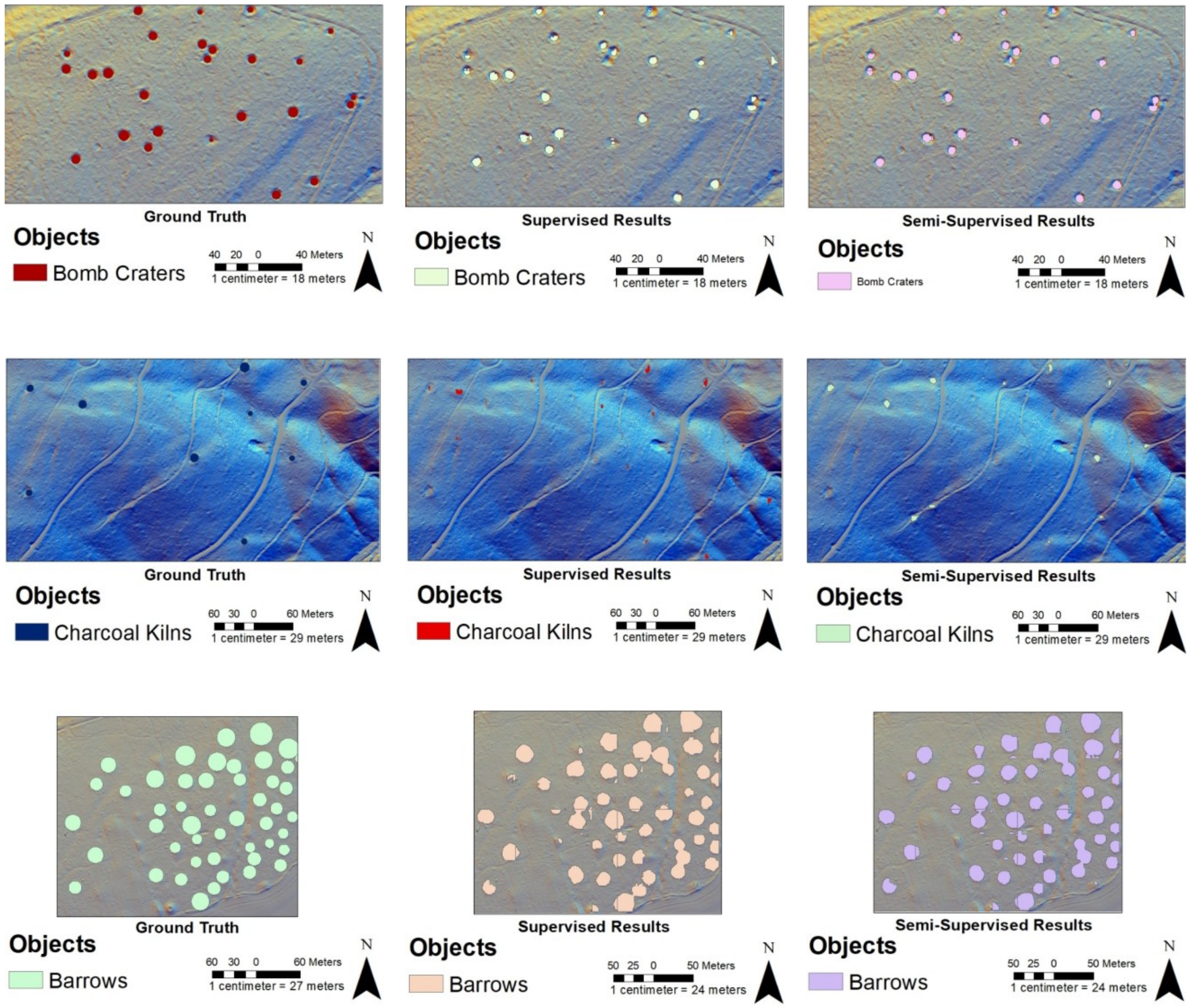


*Fig. 2. Qualitative results. Rows represent examples of bomb craters, charcoal kilns and barrows, respectively. Columns indicate ground truth, prediction by PSL, and predictions by SSL, respectively.*

Moreover, deep learning models usually work quite well with natural images since the range of values are fixed, i.e., pixels contain values in the range of 0 to 255. In DTM data, however, there is not a fixed range of values, and usual normalization techniques such as scaling input patches to a fixed range (e.g. 0 to 1 or -1 to 1) do not work well for generalizability of the trained model on unseen regions. Use of other raster data such as RGB hillshade, sky view factor, or local relief models may help improve performance since they contain values within a fixed range.

While the verification is taking place in the field, other future research directions include detection of more object classes and investigating SSL effects on tasks with more labelled examples. SSL could also be used in combination with instance segmentation models such as Mask RCNN (He et al., 2017) where the predicted label maps are more fine-grained than those of semantic segmentation models.

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# Detection of cultural heritage in airborne laser scanning data using Faster R-CNN

## Results on Norwegian data

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**Abstract:** A new processing chain for automated archaeological mapping from airborne lidar data is proposed. First, the lidar data was converted to a detailed digital terrain model (DTM), which was then converted to a local relief model (LRM) in which cultural heritage objects may be visible.

Simple faster R-CNN was used as the basis for the detection method. This deep neural network was pre-trained on the ImageNet labelled image database. Additional training was done on LRM images containing known locations of grave mounds, pitfall traps and charcoal kilns.

The classification performance was 87 % consumer's accuracy on a test set not seen during training. At the same time, the producer's accuracy was 75 %. However, all the test set images contained at least one cultural heritage object. In most landscapes, the majority of image patches of the same size may contain no cultural heritage objects visible in the DTM. Thus, the estimated producer's accuracy of 75 % may be too optimistic. On the other hand, the number of false positives appeared to be low on the Øvre Eiker unlabelled test data. In conclusion, it was demonstrated that faster R-CNN is well suited, in terms of consumer's accuracy, for automated detection of cultural heritage objects such as charcoal kilns, grave mounds and pitfall traps in high resolution airborne lidar data. However, one may expect that the method must be improved in terms of producer's accuracy in order to limit the number of false positives when applied on large areas for detailed archaeological mapping.

***Keywords:*** *grave mounds—hunting systems—charcoal kilns—automated detection— lidar—Norway*

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## Introduction

The goal of this research was to develop automated tools for improving the cultural heritage mapping in Norway. The existing cultural heritage mapping in Norway is incomplete. Some selected areas are

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mapped well, while the majority of areas only contain chance discoveries, often with bad positional accuracy.

A note on terminology: This work is multidisciplinary in the overlap between (1) computer vision and pattern recognition, (2) archaeology and cultural heritage, and (3) geographic information systems. These disciplines use the terms ‘object’, ‘artefact’ and ‘feature’ in different ways. In this paper, the term ‘object’ is used to denote something that one wants to detect and map.

Automated methods for detecting some types of cultural heritage objects from airborne laser scanning (ALS) data have previously been developed (Trier, Salberg, and Pilø, 2018). These have contributed to increasing the number of areas that are mapped well. However, the methods have a number of issues that have prevented them from being used systematically on all available ALS datasets. Template matching has been used to map pitfall traps of deer hunting systems, charcoal burning pits of iron extraction sites (Trier and Pilø, 2012) and Iron Age grave mounds (Trier, Zortea and Tonning, 2015). However, the number of false positives was high, and varied between different types of landscape. A deep neural network has been used to detect charcoal kilns (Trier, Salberg and Pilø, 2018), performing better than template matching both in terms of reduced false positive rate and reduced false negative rate, but the method was very slow.

All of Norway will soon be covered by ALS data for the purpose of creating a new national elevation model. The Norwegian Directorate for Cultural Heritage wants to use this opportunity to obtain a more complete and accurate mapping of cultural heritage in the landscape. The focus is on Iron Age grave mounds and deer hunting systems, as these are automatically protected by Norwegian law due to their age. The protection by law also applies for such sites even if they are not yet properly mapped; thus, a complete and accurate mapping is needed to manage the protection by law.

The following challenges were identified:

1. develop an automated processing chain,
2. reduce processing time,
3. reduce the number of false positives and false negatives, and
4. develop detection methods that may be applied on all Norwegian landscapes.

A recent development in deep neural networks for object detection in natural images is the region-proposing convolutional neural network (R-CNN; Girshick et al., 2014), which may also be used for cultural heritage detection in ALS data. Verschoof-van der Vaart and Lambers (2019) use Faster R-CNN (Ren et al., 2017) to detect prehistoric barrows and Celtic fields in ALS data from the Netherlands.

## Data

Three types of cultural heritage objects were used in this study (Fig. 1): grave mounds from the Iron Age (approx. 500 BC–1000 AD), pitfall traps from deer hunting systems (approx. 1–1500 AD) and charcoal kilns (approx. 1550–1900 AD). These three types of cultural heritage were selected since they are numerous in the Norwegian landscape, and thus suitable candidates for automated mapping.

ALS point cloud data was downloaded from http://hoydedata.no. This internet site provides free access to all ALS data in Norway. Vector maps of known locations of grave mounds and pitfall traps were provided as ESRI shape files by the Norwegian Directorate for Cultural Heritage. These data were extracted from the national cultural heritage database, which may also be accessed from https://kulturminnesok.no. This internet site provides search and view functionality. Vector maps of charcoal kiln locations were provided by Oppland County Administration. None of the vector maps are freely available.

The data were split into three parts, named 'training', 'validation', and 'test' (Table 1). The neural network parameters were learned from the training data iteratively by minimising a loss function. The validation data were used to select the best set of neural network parameters. The test data were then used to estimate detection performance on data not seen during training.

## Methods

### Preprocessing

The ALS data consists of a large number of individual (x, y, z) points, each being labelled with 'ground' or 'other', and also whether it was a first return from a laser pulse. By keeping only the points labelled 'ground', one may create a detailed digital terrain model (DTM) in which it is possible to see, e.g., cultural heritage structures that would otherwise be hidden by tree vegetation (Fig. 2).

The ALS point cloud data were converted to a digital terrain model (DTM) with 0.25 m pixel spacing. The DTM was converted to a simplified local relief model (LRM; Hesse 2010) by subtracting a smoothed version of the DTM. The LRM enhances local elevation differences while suppressing the general landscape topography. Thus, cultural heritage objects including grave mounds, pitfall traps and charcoal kilns may be visible (Fig. 3).

For each cultural heritage object in the vector data, a 150 m×150 m image was extracted from the LRM. In order to mimic practical use of the detection method, where the object's location is not known in advance, the image centre was moved by a random distance in both x and y, with the restriction that the entire object still be within the image. For some 150 m×150 m images, there were more than one cultural heritage object clearly visible. All these were included in the image annotations.

### Increasing the size of the training set

A common problem in automatic object detection is to obtain a sufficiently high number of training examples. With too few training examples, the neural network may perform badly on data not seen during training. A common trick to provide eight times as many training examples is to create rotated (0, 90, 180 and 270 degrees) and flipped versions. This was done for the training and validation subsets, but not for the test subset.

*Fig. 1. Top: a grave mound in Norway's largest Viking Age grave field at Vang, Oppdal municipality, Trøndelag County. Middle: a pitfall trap, Nord-Fron municipality, Oppland County. Photo: Lars Holger Pilø, Oppland County Administration. Bottom: Charcoal kiln, Lesja municipality, Oppland County.*

| | number of objects | | | | | | |
|---|---|---|---|---|---|---|---|
| object type | training | | validation | | test | | sum |
| charcoal kiln | 773 | 73 % | 190 | 18 % | 95 | 9 % | 1058 |
| grave mound | 545 | 52 % | 302 | 29 % | 199 | 19 % | 1046 |
| pitfall trap | 613 | 41 % | 565 | 38 % | 303 | 20 % | 1481 |
| sum | 1931 | 54 % | 1057 | 29 % | 597 | 17 % | 3585 |

*Table 1. Summary of vector data used for neural network training and evaluation.*

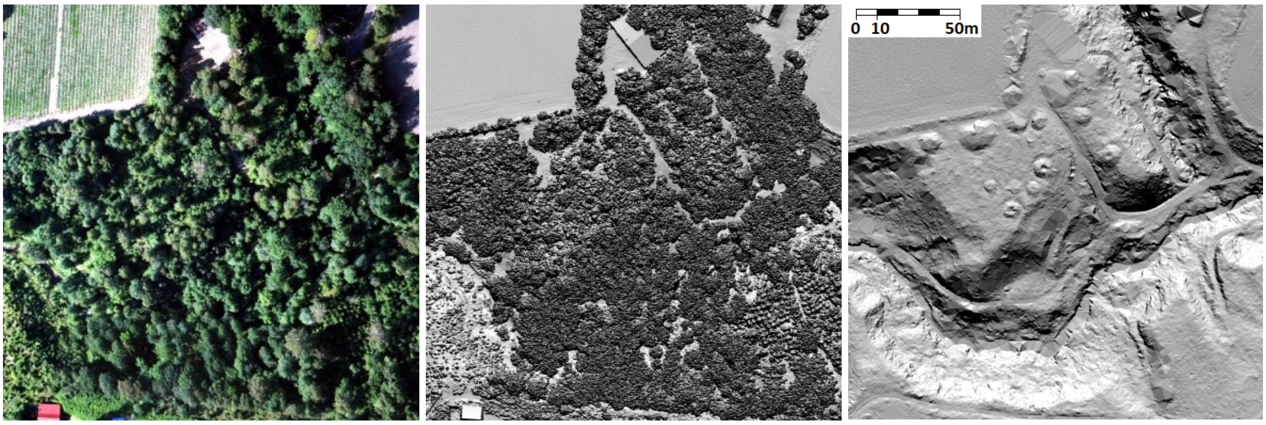


*Fig. 2. A forested area in Larvik municipality, Vestfold County. Left: air photo. Middle: digital surface model from airborne lidar data, first returns. Right: digital terrain model from airborne lidar data, by keeping only points labelled 'ground'.*

### Detection

For detection, the python code library *simple faster R-CNN* was downloaded from https://github.com/chenyuntc/simple-faster-rcnn-pytorch. For each detected object the R-CNN predicted a bounding box, a class label and a score value in the range 0.0–1.0. The score value indicated how likely it was that the detected object was a cultural heritage object, with 1.0 meaning 'very likely' and 0.0 'not likely'. Detected objects with score values lower than 0.7 were discarded.

A few modifications had to be done:

1. The list of class labels was changed to match the class labels used in the image annotations, i.e., 'grave mound', 'pitfall trap' and 'charcoal kiln'. The original code uses class labels for objects that often occur in natural outdoor images, such as 'car', 'bicycle', 'cat', 'dog', etc.
2. The downloaded code crashed if there were no detected objects within an image. We suspect that the code, which is developed for object detection in photographs, was never run on images not containing any objects of interest. However, in the context of cultural heritage detection, the normal situation in many parts of the landscape is the absence of cultural heritage objects. Thus, if-tests had to be added for the case that no objects were detected in an image.

Pre-training of the neural network was done by importing parameters learned from the VGG16 deep neural network (Simonyan and Zisserman, 2015) on the ImageNet dataset of photographs with labelled objects such as cars, dogs, etc. (Russakovsky et al., 2015). Additional training was then done on the LRM images with labelled cultural heritage objects. The neural network was then used to predict the locations and sizes of grave mounds, pitfall traps and charcoal kilns in LRM images of size 600 × 600 pixels (Fig. 4).

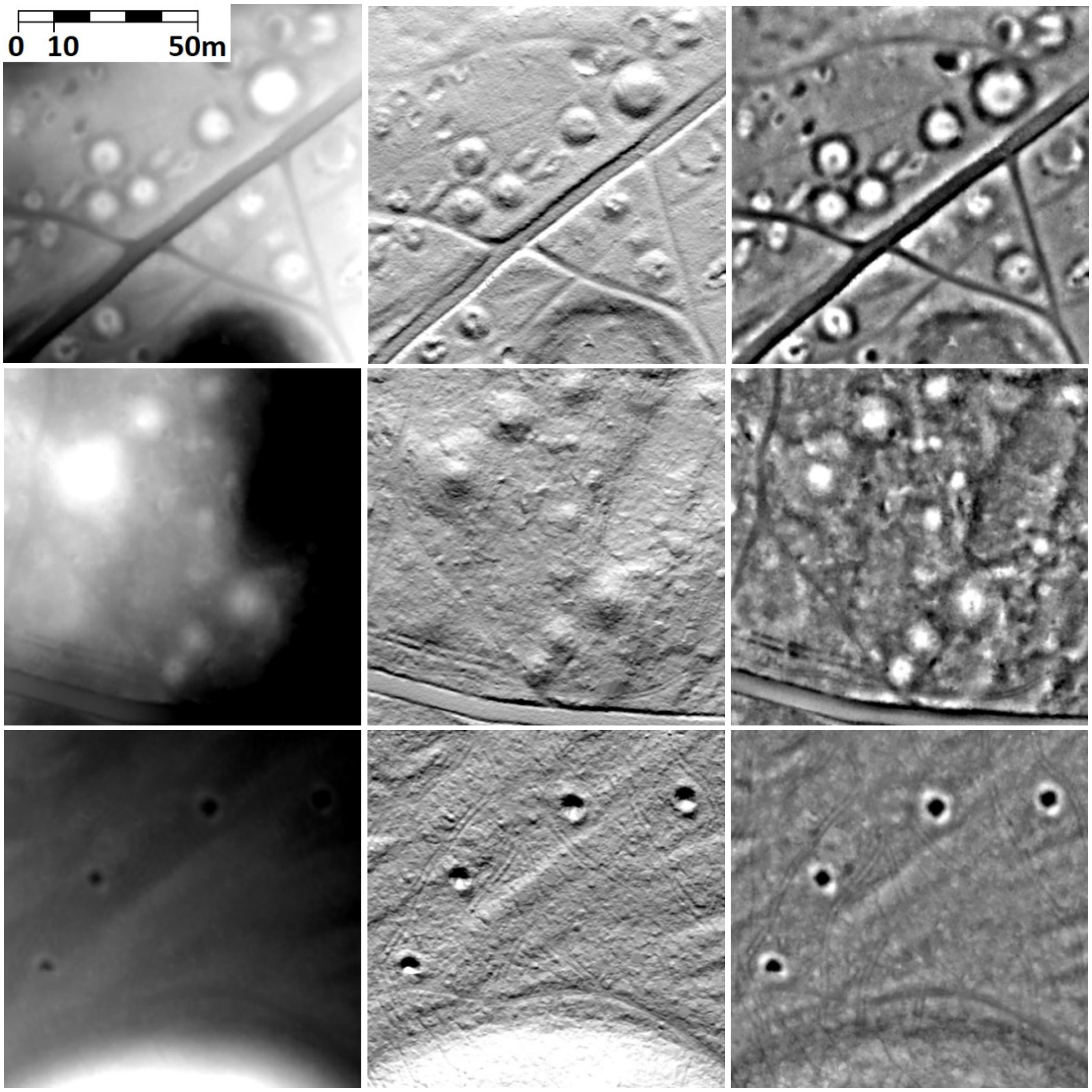


*Fig. 3. DTM visualisations. Left column: terrain elevation. Middle column: hillshade. Right column: local relief model. Top row: from Bøkeskogen, Larvik municipality, Vestfold County. Several grave mounds are visible. Middle row: from Omsland, Larvik municipality, Vestfold County. Several grave mounds are visible. Bottom row: from Nord-Fron municipality, Oppland County. A deer hunting system with pitfall traps is visible.*

## Processing chain

The preprocessing and detection methods were integrated into a python script that may be called from QGIS or started from the Linux command line. The input was a collection of LAS files, and the output was two ESRI shape files for each object type; centre points in one file and object outlines in another file. Each object outline was obtained by converting the predicted bounding box to a circle.

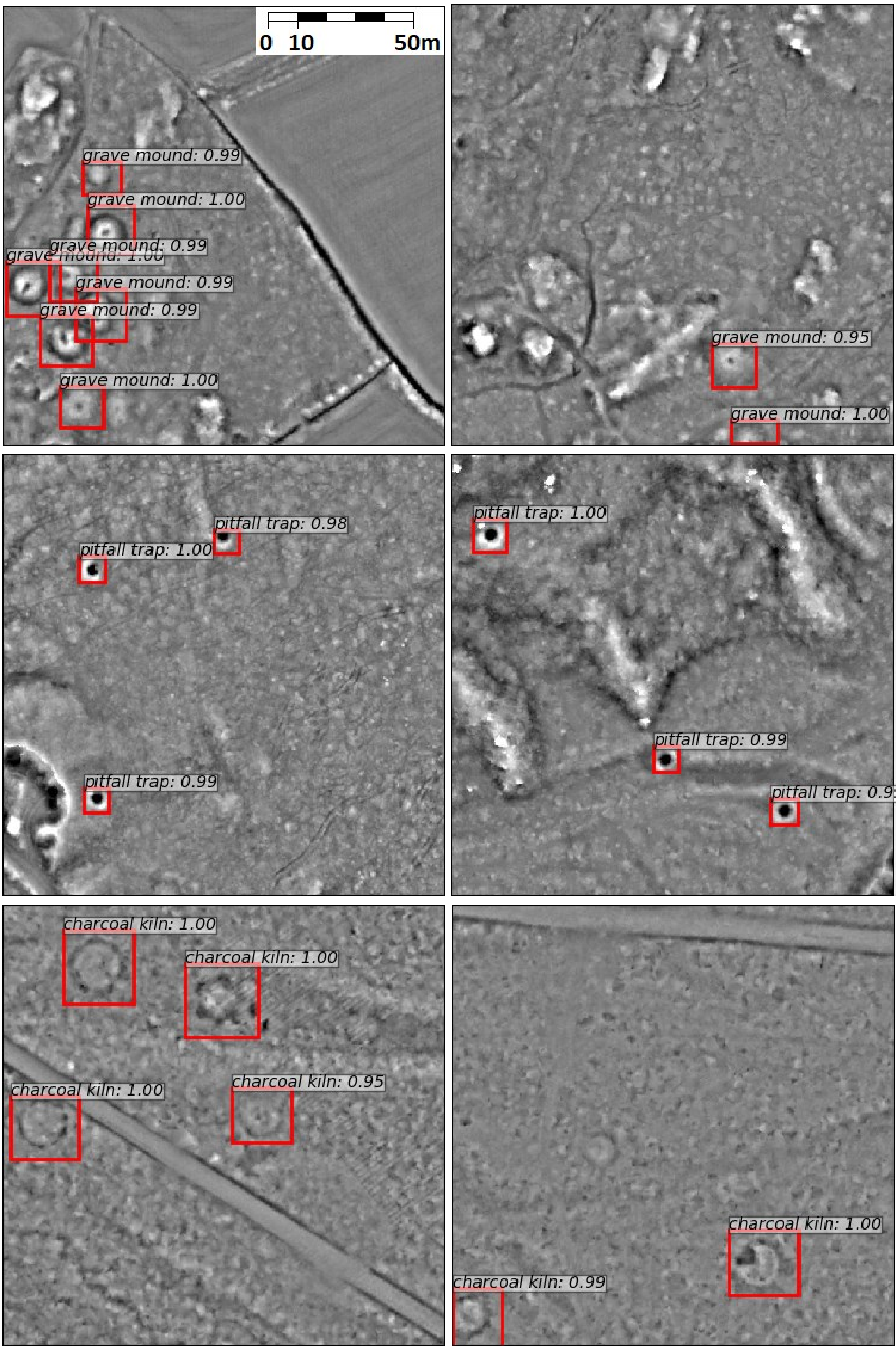


*Fig. 4. Automatic predictions, with score values (see text), of cultural heritage objects in local relief model images of 150 m by 150 m areas. Top: Predicted grave mound locations. Middle: Predicted pitfall trap locations. Bottom: Predicted charcoal kiln locations.*

## Results

By running the method on 737 test images not seen during training, the consumer's accuracy, i.e., how many of the true cultural heritage objects were correctly detected, was 87 %, and for the specific classes, grave mound 84 %, pitfall trap 86 % and charcoal kiln 96 % (Table 2). 13 % of the true cultural heritage objects were missed by the method, while less than 1 % was detected with wrong class. The producer's accuracy, i.e., how many of the predicted cultural heritage objects were true cultural heritage objects and with correct class, was 75 %.

24 % of the objects that the method predicted as being cultural heritage were in fact not. However, the latter figure may be an optimistic estimate of the amount of false positives that the method may provide. All the test images contained at least one cultural heritage object. In operational use, there may be large areas, within an ALS dataset, with no cultural heritage objects visible in the data. Thus, the potential for false positives is much larger. Evaluation of the detection and classification performance in such a setting will be done in the near future.

| | predicted class | | | | | | |
|---|---|---|---|---|---|---|---|
| true class | charcoal kiln | grave mound | pitfall trap | back-ground | sum | count | rate |
| charcoal kiln | 180 | 1 | 0 | 7 | 188 | 180 | 96 % |
| grave mound | 3 | 603 | 0 | 109 | 715 | 603 | 84 % |
| pitfall trap | 1 | 6 | 1073 | 161 | 1241 | 1073 | 86 % |
| background | 80 | 252 | 267 | 0 | 599 | | |
| **consumer's accuracy** | | | | | 2144 | **1856** | **87 %** |
| wrong class | | | | | 2144 | 11 | 0,5 % |
| false negatives | | | | | 2144 | 277 | 13 % |
| **producer's accuracy** | 68 % | 70 % | 80 % | | 2466 | **1856** | **75 %** |
| false positives | | | | | 2466 | 599 | 24 % |
| wrong class | | | | | 2466 | 11 | 0,4 % |

*Table 2. Detection results.*

The method was then used on all of Øvre Eiker municipality, an area with few recorded charcoal kilns; thus, no ground truth existed. This is the normal situation for the practical use of the method, in order to discover previously unknown cultural heritage locations. More than 1000 charcoal locations were predicted by the method (Fig. 5). A quick visual inspection (e.g., Fig. 6) confirmed that the large majority, if not all, of the predicted charcoal locations were true. Thus, they were included into the Askeladden database of all cultural heritage locations in Norway (https://kulturminnesok.no/).

## Discussion and conclusions

The classification performance was 87 % consumer's accuracy on a test set not seen during training. At the same time, the producer's accuracy was 75 %. However, all the test set images contained at least one cultural heritage object, and each image was only of a 150 m by 150 m area. In most landscapes, the majority of 150 m by 150 m patches may contain no cultural heritage objects visible in the DTM. Thus, the estimated producer's accuracy of 75 % may be too optimistic. On the other hand, the number of false positives appeared to be low on the Øvre Eiker unlabelled test data.

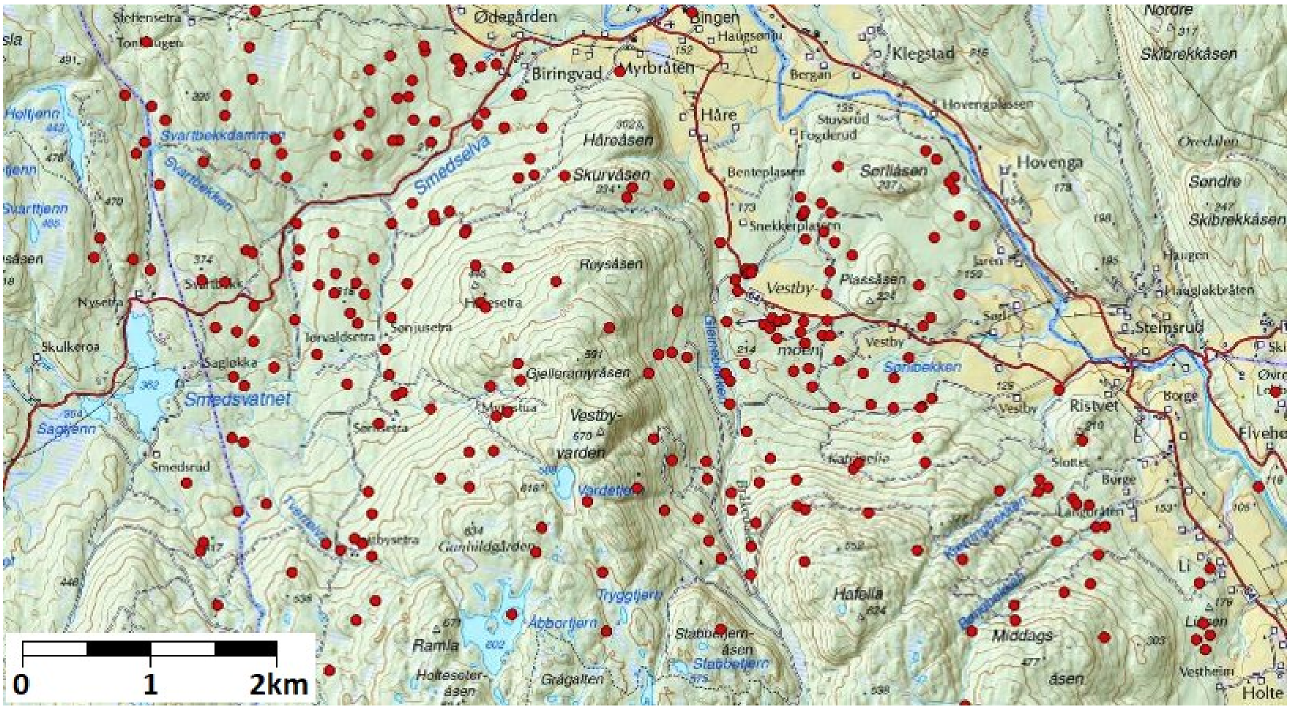


*Fig. 5. Some of the predicted charcoal kilns (red circles) in forested areas (pale green) in Øvre Eiker municipality, Buskerud County. The area shown is 10.2 km by 5.6 km.*

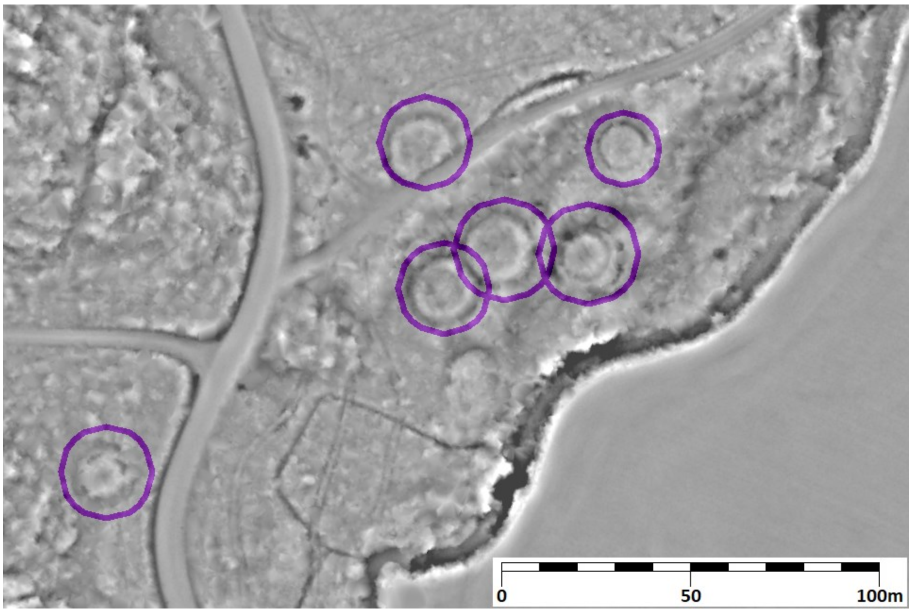


*Fig. 6. Visual inspection of six predicted charcoal kilns (purple circles) in Øvre Eiker municipality. Local relief visualization of DTM. The area shown is 240 m by 160 m.*

The method has been used on a number of ALS datasets covering a variety of landscape types, including forest, mountain, rural, agricultural and coastal areas. Although a detailed quantification of detection performance has not yet been performed, some trends were observed through practical use of the method for detailed archaeological mapping. The method performed better on charcoal kilns than on the other object types. In the inland, the method performed well on pitfall traps. This included many areas that are lacking detailed cultural heritage mapping. An unexpected bonus was that charcoal pits / tar pits were detected, albeit as pitfall traps. For grave mounds, the method was less successful. Confusion between natural knolls and grave mounds was the main problem. Still, the method may be useful by giving an overview of locations in the landscape with structures resembling grave mounds. These could then be checked visually by an experienced archaeologist, who could spot which locations need to be checked by field visits.

There are some recent projects that involve citizen volunteers to help identify which automatically detected structures are true archaeological remains. In the Chilterns in England (Morrison and Peveler, 2019; Peveler and Morrison, 2019; https://chilternsbeacons.org/wp/), citizens use an internet portal to view different lidar DTM visualisations of an area to identify and map archaeology. In the Veluwe area in the centre of the Netherlands (Lambers et al., 2019; https://www.zooniverse.org/projects/evakap/heritage-quest), an internet portal is also used. Participants are asked to mark every potential barrow, charcoal kiln and Celtic field within a 300 m by 300 m subimage. Each individual image is checked by at least eight different users. These two projects may provide ideas on how to involve citizen volunteers for visual verification of automatic detection results in Norway.

The proposed method was based on transfer learning, but in a setting that may not be optimal. The deep neural network was pre-trained on natural scene images, followed by training on DTM visualisations with labelled cultural heritage remains. As the two types of image are quite different, there is a potential for improvement by pre-training the deep neural network on a large image set that is more similar to the DTM visualisations that we used.

An issue that was observed at terrain discontinuities, e.g., a cliff, was that the local relief model visualisation might hide archaeological objects that were close to the terrain discontinuity. A possible solution could be to use another ALS visualisation, e.g. openness (Doneus, 2013).

Landauer and Hesse (2019) obtain very low false positive rates on a set of 29 000 labelled, possible charcoal kilns, with 95 % detection rate. The labels ranged from 0 = ‘certainly not’ to 4 = ‘definitely yes’. For each 40 m by 40 m image of a possible charcoal kiln, the final label is the average of the labels provided by several human users. Of the 30 false positives (i.e., images labelled with 0, but detected as charcoal kiln by the deep neural network), 15 were in fact charcoal kilns and thus wrongly labelled 0.

In order to estimate detection results for operational use, the plan is to run automatic detection on entire LAS files and not only on small image portions which contain at least one cultural heritage object. The ground truth data must be valid for all the lidar data included in the test set. The predicted cultural heritage objects will be compared with the ground truth data. One may expect to see more false positives, and thus, lower producer’s accuracy than we reported in the results section. However, one may still expect the method to be able to detect roughly the same percentage of the true cultural heritage objects.

One possible workaround to reduce the number of false positives may be to add confusion classes. This may be done by running the detection method on training and validation areas. Then, false positives may be labelled with new class names, e.g., ‘natural mound’, ‘natural pit’ and ‘natural platform’. In addition, it may be necessary to check if any false positives are actually true positives. With the confusion class objects added to the training and validation sets, training will be re-run.

Another potential for possible improvement is in replacing Faster R-CNN with another deep neural network. He et al. (2017) extend Faster R-CNN into Mask R-CNN by providing, for each detected object, an object mask in addition to the bounding box provided by Faster R-CNN. This may be beneficial if, unlike in the present study, the objects to detect deviate substantially from compact, near-circular structures. Lin et al. (2020) proposes the RetinaNet to address the imbalance of foreground versus background, a common problem in many cultural heritage detection tasks, i.e., that the absence of objects is much more frequent than the presence of objects. Code for Mask R-CNN and RetinaNet is included in Detectron (Girshick et al., 2018).

In conclusion, it has been demonstrated that faster R-CNN is well suited, in terms of consumer's accuracy, for automated detection of cultural heritage objects such as charcoal kilns, grave mounds and pitfall traps in high resolution airborne lidar data. However, one may expect that the method must be improved in terms of producer's accuracy in order to limit the number of false positives when applied on large areas for detailed archaeological mapping.

## Acknowledgements

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# Separating mounds from mounds

## Combining LiDAR with land use models for automated detection approaches

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***Keywords:*** *Semi-automatic detection—Visualization—Open Geodata—Land use models*

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doi: 10.11588/propylaeum.747.

## Introduction

LiDAR-derived digital terrain models revolutionized archaeological prospection in the last two decades. Using the new technique, area-wide detections of field monuments hidden under dense vegetation became possible and archaeologists found new sites even in well-known areas. Concerning the drawbacks of the commonly used hill shading visualization, many other visualizations were invented to enhance visibility of interesting structures. However, analysing terrain models is still mostly done by hand in well-defined investigation areas. Vice versa, for a province-wide detection of field monument, automated approaches are necessary to fully exploit their potential. This also applies to the state of North Rhine-Westphalia (NRW) in western Germany. On the one hand, archaeologists benefit from the Open Geodata principle, which provides up-to-date spatial data, such as digital terrain models, free of charge. On the other hand, there are not enough resources to take the chance for a province-wide prospection using these data in a reasonable amount of time.

Therefore, geographers from the Ruhr University Bochum and archaeologists from the Westphalian archaeological agency are developing workflows for an automated and time-efficient analysis of the available terrain models. To reduce processing time, e.g., settlements and other sealed areas are rejected. Finally, potential field monuments are flagged and sorted by probability. This way, archaeologists are able to interpret the most promising results at first without losing those that appear eroded. Some of the preliminary results were already published in Meyer et al. (2019).

This paper will demonstrate two things. Firstly: discriminating between archaeological interesting and uninteresting areas is possible and appropriate to avoid misclassifications. Secondly: the topics of LiDAR visualization and automated detection are interdependent. More precisely, traditional

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hillshade visualizations should not be used for Object-based Image Analysis (OBIA). E.g., Difference Maps should be preferred.

## Determining archaeological interesting areas

The government of NRW provides a variety of spatial datasets free of charge. The land use model *BasisDLM* is used to determine archaeological interesting areas (*positive*) and to reject those where field monuments cannot be preserved in the terrain (*negative*).

The land use model consists of a bunch of shapefiles, each including a certain type of land use as polygon-, line- or point features. Evaluating polygons, such as forests, pastures or residential areas, is relatively easy because unsealed areas are most likely to be positive, whereas the others are negative. Line and point features, however, have no width or diameter, in contrast to their modern real-world counterparts such as streets or windmills. Therefore, their width has to be derived from the attribute table or determined as precise as possible for every type of object. These width values are then used as radii for buffer zones, representing the negative area around each feature (Fig. 1). Starting with well-defined investigation areas to derive the width of all features, the buffering was finally done for the whole province of Westphalia. This way, most non-archaeological mounds and other modern structures are rejected from the detection (Fig. 2, Meyer-Heß, 2020).

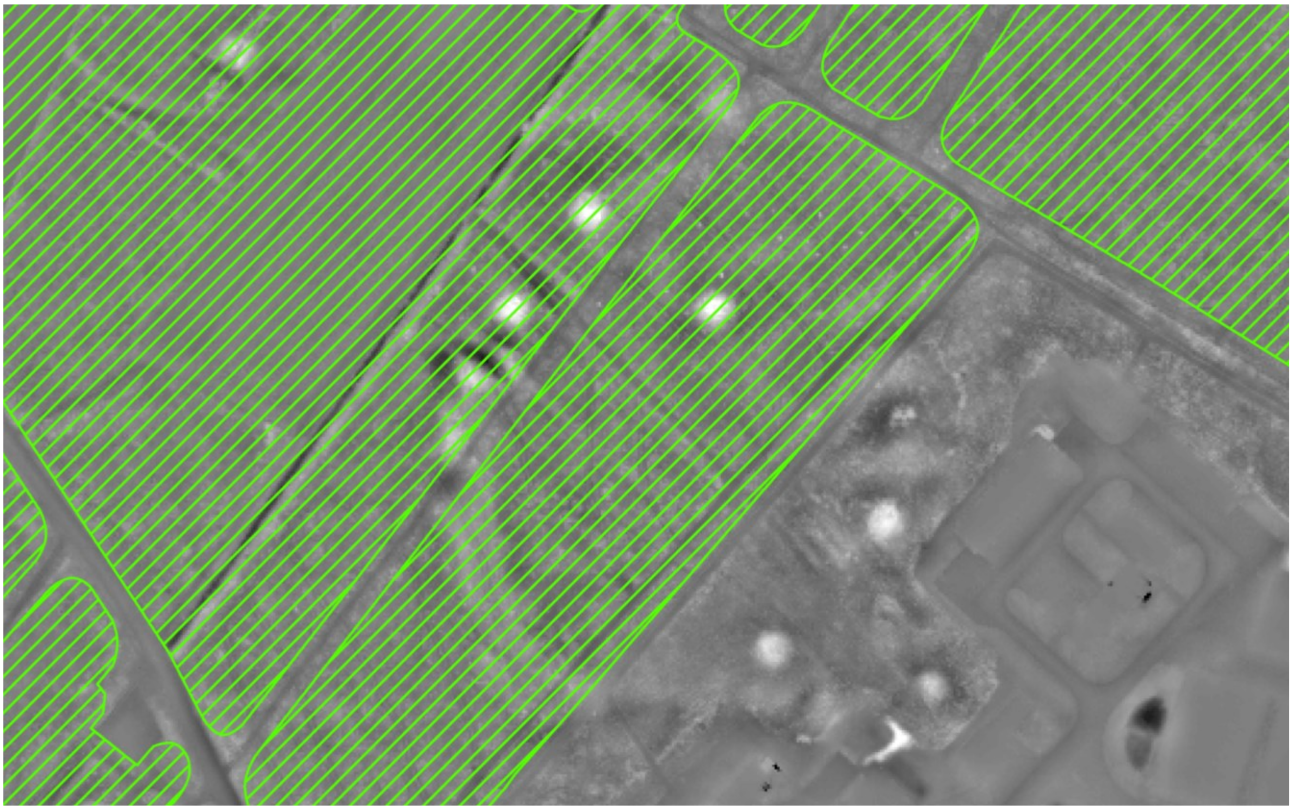

*Fig. 1. Difference Map of an investigation area in Haltern. The brighter a pixel, the more elevated it is compared to the surrounding relief, whereas dark colors are below. The positive layer, to which the search is limited to (green), is overlaying (Data Source: Land NRW, dl-de/by-2-0).*

*Fig. 2. Non-archaeological mound made of asphalt in Wuppertal (© M. Fabian Meyer-Heß).*

## Automated detection using OBIA

For the classification, OBIA, implemented in *eCognition Developer* by Trimble, is used. This technique does not classify single pixels but objects representing homogeneous areas within an image. In a DTM, they correspond to areas of the same height. Objects are generated in the initial segmentation step that is executed perfectly when the object borders match those of their corresponding real-world objects.

Afterwards, statistical values are calculated for every object. Some of which refer directly to the object (e.g. length and width) and some to its neighbors (e.g. rel. border to brighter objects). From these, the user can choose features to describe classes. This is the advantage over pixel-based approaches because objects can be addressed in a relation to their neighbors and therefore be discriminated by their location, which is essential for the detection of field monuments. In terms of OBIA, remnants of a Motte-and-Bailey castle can be described as a local maximum (the motte) or as an object completely surrounded by darker (lower) objects, which is in close proximity from a ring-shaped local minimum (a ditch surrounding the motte). All steps are included in a *ruleset* that runs fully automated, exports the classification results to GIS-compatible shapefiles and can be transferred to other projects.

### OBIA and its dependencies on visualizations

Although OBIA does not ‘see’ an object in the way the human eye does, it nevertheless benefits from special terrain visualizations like the Difference Map that was originally developed for manual interpretation. Because hills and valleys are removed, contrast increases significantly but most importantly, all monuments appear in a levelled situation.

This is necessary because object borders in LiDAR datasets follow the contour lines, making field monuments invisible to OBIA if they are located on a hillside. Fig. 3 demonstrates this issue as the castle on the left side (a) cannot be detected because the objects where derived from a regular DTM. On the right side (b) the hill is removed (Difference Map) and motte and bailey stand out against the surrounding area even though they are almost eroded completely.

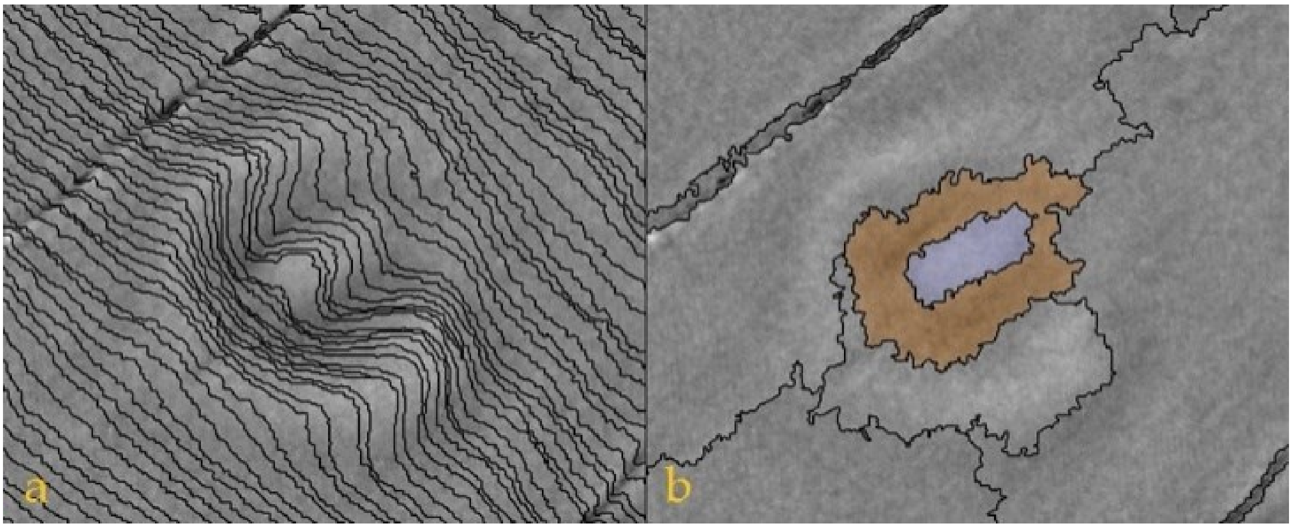


*Fig. 3. Difference Maps of a highly eroded Motte-and-Bailey castle on a hillside in Warburg with overlaying objects derived from a regular DTM (a) and from a Difference Map (b) (Data Source: Land NRW, dl-de/by-2-0).*

## Mound detection

Mound detection in OBIA is relatively straightforward. In terms of OBIA, the task is to find round local maxima. They are not classified binary but in five classes, that were derived from reference mounds in different stages of erosion. This is a similar result organizing approach to that of Trier et. al. (2015).

Table 1 provides an idea of what is possible under good circumstances. The overall decreasing correctness is no surprise because the class descriptions get wider in order to find possible eroded mounds as well. Completeness is 100 % by definition, because all 173 reference mounds defined the classes. The black numbers where generated using the outdated workflow without considering the land use, whereas the blue numbers are considering the additional information. These are significantly higher demonstrating that land use models are useful and should be used not only for mound detections but for manual prospection as well.

| Class | TP | FP | Total | Correctness | Δ |
|---|---|---|---|---|---|
| 1) ideal | 14 | 1 / 0 | 15 / 14 | 93 % / 100 % | + 7 % |
| 2) … | 20 | 19 / 10 | 39 / 30 | 51 % / 67 % | + 16 % |
| 3) … | 65 / 64 | 260 / 147 | 325 / 211 | 20 % / 30 % | + 10 % |
| 4) … | 52 | 578 / 415 | 630 / 467 | 8 % / 11 % | + 3 % |
| 5) highly eroded | 22 | 1227 / 911 | 1249 / 933 | 2 % / 2 % | + 0 % |
| Total | 173 / 172 | 2085 / 1483 | 2258 / 1655 | 8 % / 10 % | + 2 % |

*Table 1. Results of a mound detection in Haltern. Blue numbers were generated using the land use model.*

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# Beacons of the Past

## Visualising LiDAR on a large scale

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***Keywords:*** *LiDAR—Digital Terrain Model—Visualisation—Landscape—High-Resolution DEM—Archaeology*

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doi: 10.11588/propylaeum.747.

## The Project

The *Beacons of the Past* (*BotP*) project was developed by the Chilterns Conservation Board (CCB) to investigate the Chiltern Hills of Southern Britain, a landscape that has a pivotal role in understanding human colonisation of upland spaces in post-glacial Britain, the development of farming on marginal soils, and the evolution of power and regional tensions of the later prehistoric period.

The Chilterns Area of Outstanding Natural Beauty (AONB) provides an ideal test case for a landscape-scale, high resolution archaeological LiDAR study. The key reason for this is the Chiltern woods. Over 22 % of the 833 km$^2$ AONB is today covered by woodland (more than double the average for England – National Forest Inventory 2017[1] and Forest Research Statistics 2019[2]), and about 60 % of this has been found to be “ancient woodland,” continuously wooded since before AD 1600 (Natural England, Ancient Woodland Inventory, 2012[3]).

Environment Agency (EA) LiDAR data has wide, and growing coverage of the UK. In the Chilterns, large areas are still yet to be surveyed by EA, with completion planned by 2021. The EA data which does exist for the region has often been flown at 1 m resolution. At this resolution many archaeological features are not identifiable. This is particularly exacerbated under tree cover, where ground point densities are inevitably lower than for open ground.

A bespoke LiDAR dataset was therefore viewed as being of great benefit for enriching the understanding of this landscape, and through funding from the National Lottery Heritage Fund and other partners, the largest bespoke high-resolution archaeological LiDAR survey yet undertaken in the UK was commissioned. Encompassing 1400 km$^2$ (Fig. 1) and flown at a minimum resolution of 16ppm, extending to 27ppm in open ground, utilising the Riegl Q1560 LiDAR sensor, the survey offers not

[1] https://www.forestresearch.gov.uk/tools-and-resources/national-forest-inventory/

[2] https://www.forestresearch.gov.uk/tools-and-resources/statistics/statistics-by-topic/woodland-statistics/

[3] https://naturalengland-defra.opendata.arcgis.com/datasets/45d3eebaebf847ac8c9f328091af5571_0

only the potential to reveal hundreds of new archaeological sites, but also in keeping with the mission of the CCB, point cloud data can be used to record and monitor tree canopy and hedgerow health.

Where the data overlaps with EA existing data, comparisons can be made to observe erosion and monument preservation between the EA survey and the project's, and any future re-flying of the region by the EA can also be used for comparison to the *BotP* survey.

## Visualisation approaches

The last few years have seen vigorous research into the creation of different visualisation techniques of LiDAR datasets in order to maximise the visibility of archaeological remains within them. The fallibility of single directional hillshade as a technique is well-understood by knowledgeable LiDAR practitioners, but with the ever-growing acknowledgement of LiDAR's effectiveness for archaeological survey, and the growing availability and ease of use of datasets mean there are large numbers of users relying solely on a single hillshade.

Whilst it is agreed that there is much customisation of hillshade processing which can be done to tease out more information (Fig. 2), the BotP team supports Štular et al. (2012) in the assertion that there is no single best visualisation method but that sky view factor (SVF) if preferred over hillshade in most instances (Fig. 2). Due to the prodigious scale of the survey, analysis of the data will rely heavily on the assistance of citizen science (see below). Therefore, the visualisations that are presented to the public must make maximum use of the wide array of possibilities, rather than limit the visibility of features to the sole use of hillshades. Current layers offered are (above hillshade) SVF and Local Relief Model (LRM), but other methods, particularly the new 'combined visualisation' approach of Kokalj and Somrak (2019), are being tested.

The growing publication of tailored, easy to use software, and ever developing computing technology with decreasing costs, have made 3D visualisation methods far more accessible, and it remains to be tested whether these have advantages of interpretability over traditional 2D approaches. *BotP* offers comparative trials of survey for archaeology across the two methods, to see whether 3D really does offer a more efficient, more interpretable alternative, and whether potential negative aspects such as expedience or cost are mitigated by greater effectiveness.

## Citizen Science

The project has worked to create a bespoke web-GIS and heritage asset management system, to allow ready, free, licence-less access to view data layers including several LiDAR visualisations, aerial photography, and large scale modern and historic mapping. Following on from the arguments of the project has put the task of interpreting the landscape into the hands of the public, understanding that 'experts' do not know the landscape as well as those who live in it, work in it, and in many cases have spent decades exploring it (Duckers, 2013).

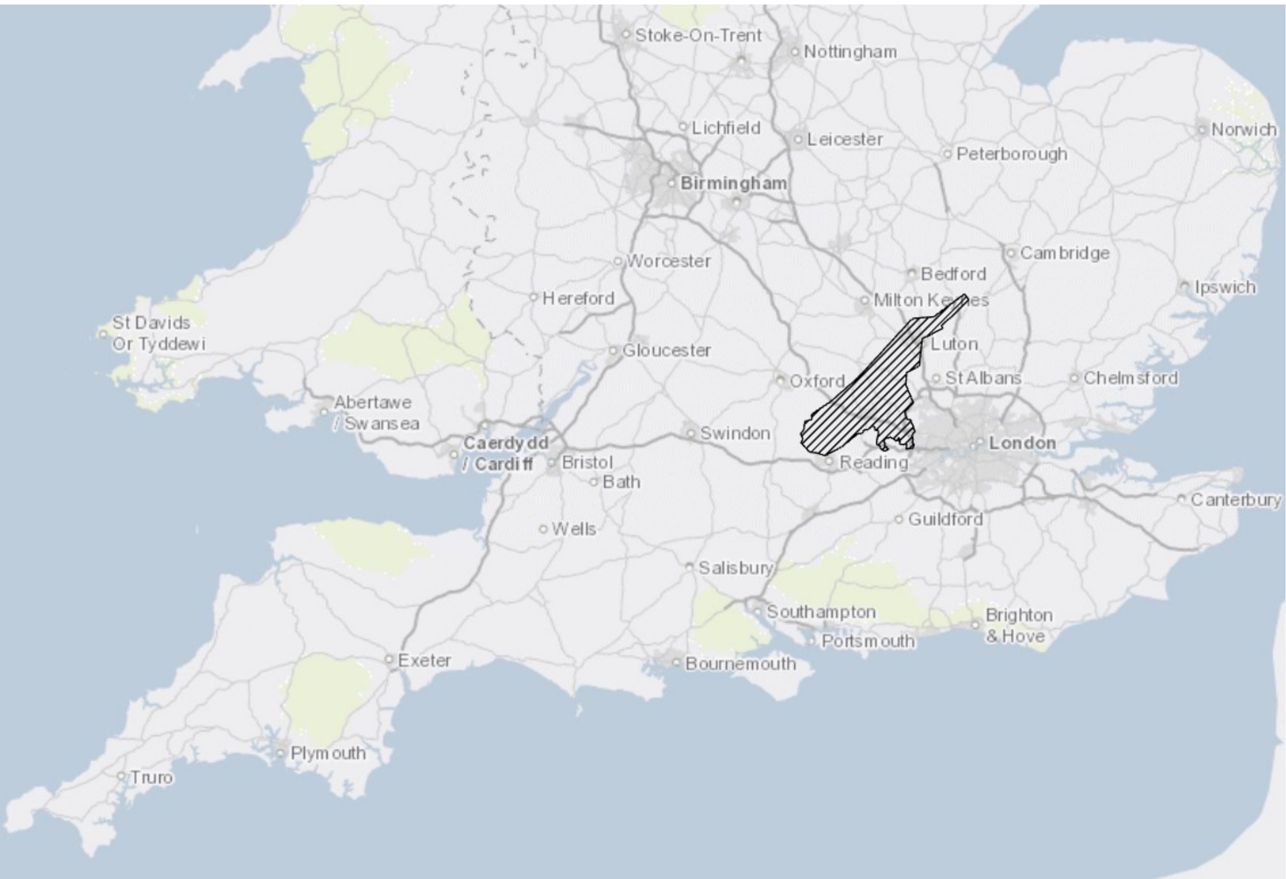
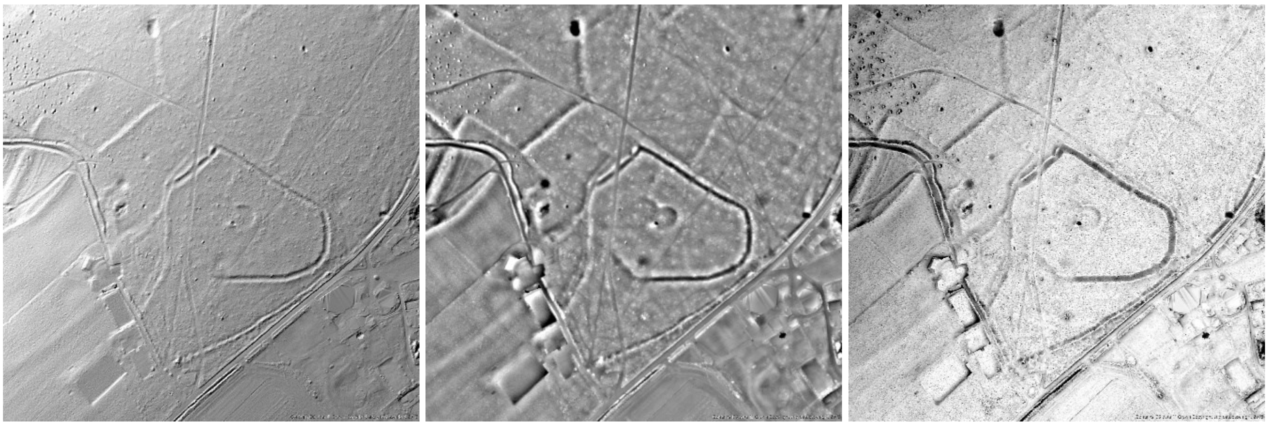



*Fig. 1. Location of Chilterns Hills in the United Kingdom; lined area is the coverage of LiDAR survey.(© CCB; basemap © Crown copyright)*


*Fig. 2. Two single hillshade images of Maiden Bower hillfort, Bedfordshire, produced using RVT 1.3, of the same area: note the different levels of detail discernible in different parts of the image, and in particular the presence-absence of subtle field boundaries to the east and north of the hillfort, depending on the illumination azimuth.(© CCB)*



a b c

*Fig. 3. Three visualisations of Greenfield Copse, Oxfordshire. a) single hillshade; b) LRM; (c) SVF. Note the increased visibility of prehistoric field systems in northeast of (b) and greater detail of small features at southwest of c). (© CCB)*

This approach has the benefit of assisting to interpret and map archaeology over the vast survey area. Papers by Duckers (2013), Curley et al. (2018), and Lambers et al. (2019) have reported on the 'efficiency' of different techniques for analysts, both expert and non-expert. The *BotP* web portal explicitly asks its citizen users which visualisation technique they have used for recognising a feature, so a large dataset will be created showing the preference for and effectiveness of the different visualisation techniques offered to them.

A citizen science approach also allows a route to unprecedented engagement with the public. Not only is this data type relatively restricted to expert users, but geographic information systems (GIS) are also generally restricted to professional users, by both licence fees and knowledge barriers to their use. We are presenting a simple, user-friendly, well-documented GIS system which allows engagement with audiences, many of whom will never have heard of LiDAR or GIS, and indeed many of whom may not otherwise have been interested in archaeology. It may also form a useful learning tool for archaeology or geography students, or professionals as Continuing Professional Development training.

A full range of activities beyond just the citizen science LiDAR transcription, including workshops, talks, activity days, and field-checking sessions, run across the AONB, opens access up to an even wider range of participants, with 1.6 million people living within 8 km of the AONB, and the more than 50 million visits the AONB attracts every year.[4]

## Conclusion

Beacons of the Past is shedding light on the previously hidden landscapes of the Chiltern Hills. The challenges of both terrain extremes and sheer scale of datasets make the survey a perfect testing ground for a wide array of visualisation techniques and blended methodologies. Harnessing the power of Citizen Science will maximise both the number of features identified and provide an indication of the most reliable approaches for rapid identification and transcription of archaeological features from raster images.

[4] https://www.chilternsaonb.org/conservation-board/management-plan.html (Accessed: 19 July 2019).

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# Classifying objects from ALS-derived visualizations of ancient Maya settlements using convolutional neural networks

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***Keywords:*** *archaeology—deep learning—convolutional neural networks—digital elevation model—airborne laser scanning—lidar*

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## Introduction

Archaeologists engaging with remote sensing data rely heavily on manual inspection. This presents a major bottleneck in the data analysis pipeline, preventing them from keeping up with ever increasing data volumes, and creating a pressing need for computational methods that can automate data annotation and analysis.

Within archaeological community, critics of computational methods like to stress the superiority of human vision for identification of archaeological objects from remote sensing data. For the purposes of manual inspection, raw data is often converted to a representation that is most intuitive for visual interpretation. In this regard, the airborne laser scanning data (ALS) data used in archaeological prospection is usually visualized, e.g. the ALS-derived digital elevation model (DEM) represented as Visualization for Archaeological Topography (Kokalj and Somrak, 2019). Meanwhile, in the field of computer vision we see proliferation of deep convolutional neural networks (CNNs), which mimic the human visual system and achieve state-of-the-art performance on optical images. While there have already been applications of CNNs in remote sensing, only a handful of them concern ALS data in archaeological prospection (Verschoof-van der Vaart and Lambers, 2019; Trier et al., 2019).

We therefore propose a CNN-based method to distinguish among various types of anthropogenic objects in ALS visualizations. Development of such a CNN requires incorporating manually annotated data with thousands of samples. While manual annotation of data from our own ALS survey took several man-months, having in mind that thousands of square kilometers of similar data have already been collected in other surveys, further manual work can be minimized if the annotation process is automated.

## Data and Methods

220 km² of ALS data have been collected around Chactún, one of the largest Maya urban centers known so far in the central lowlands of the Yucatan peninsula. More than 12,000 anthropogenic objects of three different types (building, platform, and aguada—artificial rainwater reservoirs) were manually annotated over 130 km² (hereinafter referred to as the analyzed area).

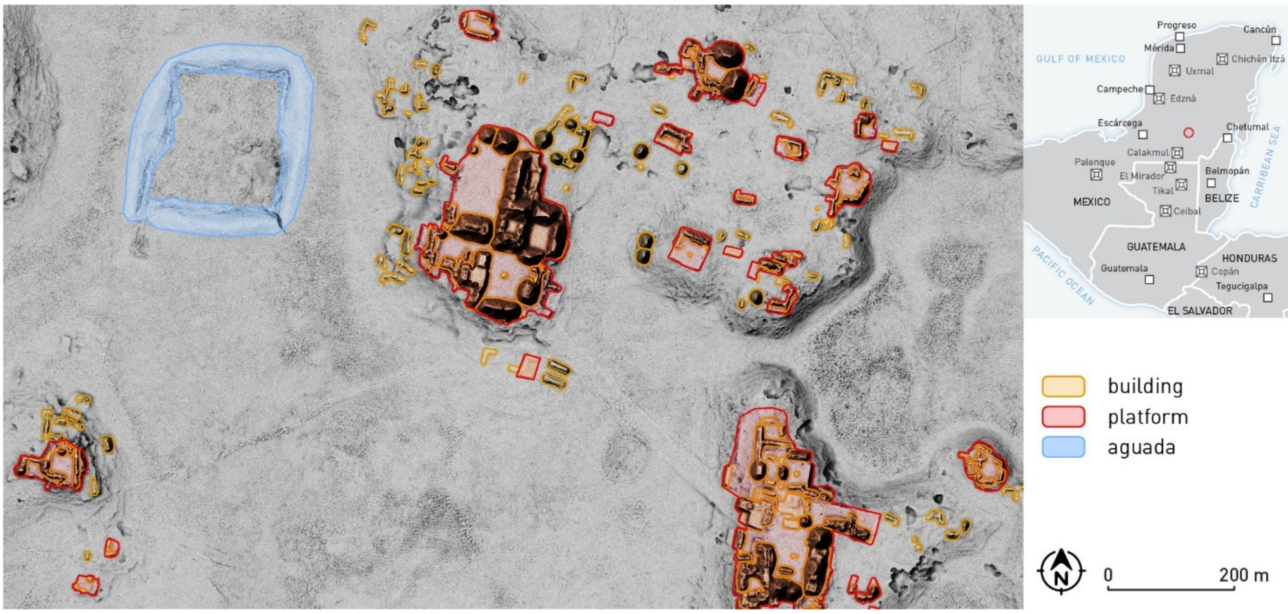


*Fig. 1. Chactún with annotated data. (© M. Somrak)*

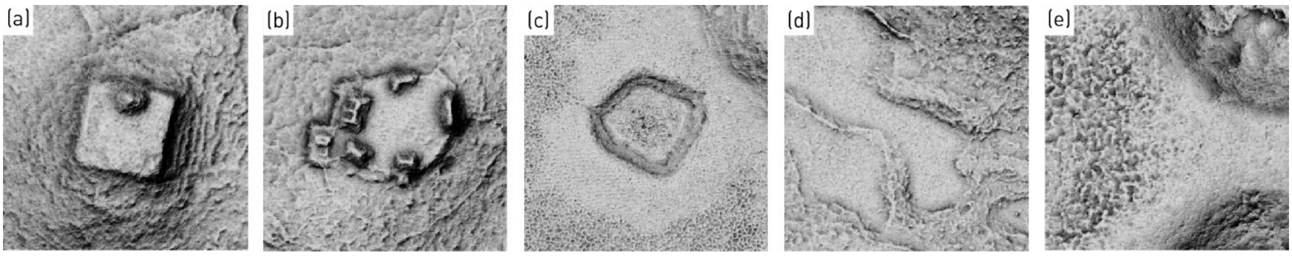


*Fig. 2. Examples of generated data samples for different classes: a) platform, b) platform, c) aguada, d) terrain, e) terrain. Platforms on images a) and b) contain one and six buildings, respectively. (© M. Somrak)*

Method development and implementation is split into several stages, of which the first is currently being developed and is presented in this paper. Advancements at every stage will build upon the previous to produce results, which are gradually closer to the final desired outcome—a model, which could potentially replace manual annotating. Method development includes: 1) Image classification *(classification of ALS visualizations of individual objects);* 2) Object recognition (*recognition and localization of different objects on ALS visualization of a larger area);* 3) Semantic segmentation *(location and exact boundaries of objects);* 4) Instance segmentation *(segments joined into individual instances, counting instances*); and 5) Repetition of previous implementation steps using elevation data (DEM) instead of ALS visualizations.

The analyzed area was split 80/20, to account for training and validation sets. Samples were generated for each class of anthropogenic objects; square bounding boxes were enlarged with a 30 pixels buffer. For negative samples, i.e. samples of natural terrain, it was assumed that areas of 128 × 128 pixels that do not contain any annotated objects can be considered. The total number of terrain samples equals the combined number of all anthropogenic samples (Table 1).

| Class | | | Number of samples | Percentage of annotated samples from total area of 220 km$^2$ | Class recall (at 4 classes) | Class precision (at 4 classes) |
|---|---|---|---|---|---|---|
| anthropogenic objects | structure | building | 9303 | ~ 60 % | 96 % | 93 % |
| | | platform | 2110 | ~ 60 % | 63 % | 78 % |
| | aguada | | 173 | 100 % | 79 % | 70 % |
| other / natural | terrain | | 11,586 | / | 98 % | 98 % |

*Table 1. Types and number of different objects annotated in our ALS survey data.*

The VGG16 model (Simonyan and Zisserman, 2014) was used for transfer learning for the deep CNN model. VGG16 is a network with 16 convolutional layers and very small (3 × 3) convolutional filters. It has already been successfully applied in a few other remote sensing studies, where it obtained state-of-the-art results for some specific datasets (Wang et al. 2017). The VGG16 model used in this study was implemented in Python, using Keras and TensorFlow libraries, with modifications. Our dataset images were rescaled for input size of 128 × 128 pixels just before they were fed into the network. Three variations of the model were made to distinguish between two, three, or four different classes. Output of each of these model variations is one of the class values:

a) *terrain* or *structure*—where class *structure* is introduced as a joined class of buildings and platforms
b) *terrain*, *building* or *platform*
c) *terrain*, *building*, *platform,* or *aguada.*

## Results

Model performance was tested for class recall, class precision and overall model accuracy. Accuracy was lower for two and three different classes and higher at four classes (Table 1), achieving overall accuracy of 94 % at four classes.

### Discussion

The neural network's low performance on the aguada class is likely a result of its low sample count, therefore data augmentation should be considered to overcome the issue. All of the samples also have to be checked for accuracy of annotation. The overlap between the majority of building and platform objects resulted in the two classes' datasets containing very similar images. Probably as a result, the neural network did not so successfully distinguish between the two classes. Misclassified terrain samples were usually classified as structures (or buildings/platforms). After manual inspection of misclassified samples, it was evident that terrain samples did indeed contain anthropogenic objects that have not been annotated. This was a known potential issue from the beginning, as some objects—such as terraces, tracks, walls, quarries and other less common anthropogenic features were known to be present but were not annotated.

## Conclusion

It was shown that CNNs can be successfully used to classify ALS-derived visualizations of different anthropogenic objects against natural terrain. Main misclassification issues have been identified and further work on data annotation, data augmentation, neural network fine-tuning and design modifications should further improve the classification accuracy.

## Acknowledgements

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# Session:
# Heritage-BIM between survey, planning and management

Piotr KUROCZYNSKI | Claudiu SILVESTRU

## Heritage-BIM between survey, planning and management

Chairs:
Piotr KUROCZYNSKI, Hochschule Mainz – University of Applied Sciences, Germany
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***Keywords:*** *Historic/Heritage BIM—3D modelling—3D reconstruction—data management.*

*Building Information Modelling* (BIM) is the answer of contemporary building industry to improve the collaboration of all specialist engaged in the planning, construction and facility management process. BIM as the collaborative methodology to plan and manage crucial information is based on the data exchange format *Industry Foundation Classes* (IFC). As ISO 16739:2016 IFC ensures the sustainability and interoperability of the object-based information.

The growing interest in the cultural heritage—recognized as being crucial as well for the local identity as for economic development of the regions—increases the projects concerning the protection, conservation, restoration, and dissemination of cultural heritage. The instrumentalization of BIM/IFC for this kind of projects leads to the extension of the BIM concept towards the *historic* or *heritage* BIM (hBIM)[1]. The consideration of the BIM concept as an emerging technology that enables us to understand, document, advertize, and virtually reconstruct the built heritage is not new. Besides the aforementioned potentials we still have many restrictions and challenges when using BIM supporting software to handle heritage sites and/or buildings for survey, documentation and dissemination.

How to capture and describe the heritage site/building in BIM-supporting software? What are the potentials and challenges? Are there hBIM standards or guidelines? And how practicable are they? How flexible is the IFC data model behind the 3D model? How does hBIM meets the requirements of the building history researchers, conservators, project developers, planners and managers of heritage sites/buildings?

This session considered all these aspects. Papers both on BIM/IFC theory as well as examples of BIM-conform 3D modeling of destroyed or still existing cultural heritage in practice in the real world were welcomed.

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# Quantitative Visualization of Secular Changes based on 3D Viewpoint Estimation for archaeological heritage maintenance

## A Case Study at Barber Temple Ruins in Bahrain

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**Abstract:** The historical structures, which have cultural heritage value, must be continuously maintained and passed down to the next generation. Excavated archaeological sites are backfilled for conservation; however, many of them are not systematically maintained and are often found to have been destroyed or weathered. Moreover, many archaeological sites do not have detailed records of their preservation and restoration after the excavation finished. The purpose of this study is to grasp the change of the appearance of the structure from the excavation to the present time with high accuracy in the Barbar Temple in Kingdom of Bahrain. Since estimating the viewpoint of a photograph taken in the past enables overlaying the current situation from the same viewpoint, it is possible to visualize the changes by aging accurately. This paper also shows a method for quantitatively examining the changes over time by putting a virtual gridded surface with actual size into the same 3D data of the reconstructed archaeological site. The authors verified the accuracy of the method by experiments performed in prepared setup, where the known grand truth values are available in advance. This paper reports the effectiveness of the proposed method based on the case of applying this method to archaeological sites in Bahrain as well as the expected accuracy based on the quantitative evaluation.

***Keywords:*** *H-BIM—4D—PnP Problem—3D measurement*

**CHNT Reference:** Mori, Naoki; Almahari, Salman; Suemori, Kaoru; Suita, Hiroshi, and Yasumuro, Yoshihiro. 2021. Quantitative Visualization of Secular Changes based on 3D Viewpoint Estimation for archaeological heritage maintenance. Börner, Wolfgang; Kral-Börner, Christina, and Rohland, Hendrik (eds.), Monumental Computations: Digital Archaeology of Large Urban and Underground Infrastructures. Proceedings of the 24th International Conference on Cultural Heritage and New Technologies, held in Vienna, Austria, November 2019. Heidelberg: Propylaeum.
doi: 10.11588/propylaeum.747.

## Introduction

In recent years, aerial photography by UAV (Unmanned Aerial Vehicle) and laser scanning technology allows to obtain detailed 3D geometry information of outdoor structures easily. In the field of cultural heritage preservation and restoration, many projects use these techniques to maintain accurate records and to promote documentation with rich information. However, cultural heritage, especially archaeological sites, are allocated human resources and budget for excavation, but often are not systematically maintained after the excavation is completed. This study focuses on one such archaeological site, the Barbar Temple site in the Kingdom of Bahrain.

The Barbar Temple was excavated and backfilled repeatedly in the 1950s by Danish investigators (Andersen and Hojlund, 2003) and was partially restored and repaired from time to time. In Fig. 1, the upper photos show the state at the time of the excavation, and the lower photos show the current state. The red circles indicate the same spot in the upper and lower photos, but the current appearances have changed so much through the decades that it is difficult to identify. Besides, the history of damages and repairs since the excavation is rarely recorded. And thus, many maintenance items have not been communicated even among the officials in the Ministry of Culture. Therefore, it is desirable to accurately grasp the changes over time in order to accurately grasp the situation since the excavation and to promote the preservation and utilization of archaeological sites in the future.

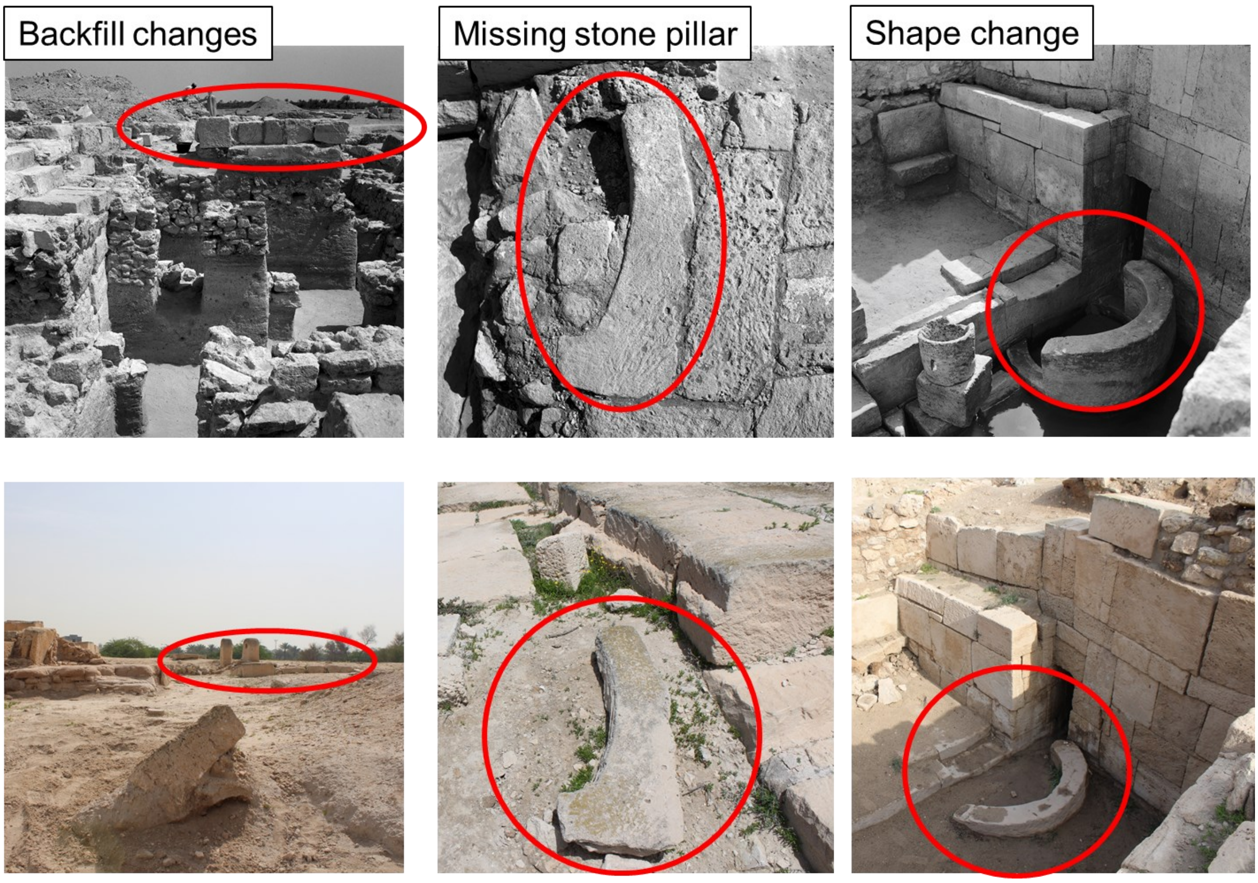



*Fig. 1. Example of changes over time in appearance (© N. Mori et al.).*

In this research, the authors propose a system to visualize the past and present aging of cultural heritage, and to observe the differences with high accuracy, using limited photographs at the time of the excavation as clues. The purpose of this research is to enable maintenance workers to more accurately grasp the actual situation by quantitative observation of aging structures and use it as a clue for future repair and restoration.

## RELATED WORK

### Information Modelling in Cultural Heritage

In promotion of digital technology for managing and maintenance of cultural heritage, a concept of Heritage-BIM (H-BIM) (Murphy et al., 2009, Volk et al., 2014), which applies BIM (Building Information Modelling) used in modern construction, is attracting attention as a method to systematically accumulate information related to maintenance, such as maintenance and repair of cultural properties. H-BIM applies a 3D model of a historical structure created based on actual measurements to objects such as building materials defined by IFC (Industry Foundation Classes) to assign attributes to contain a variety of items, including deterioration status and maintenance records. Then, various information related to historical structures can be centrally managed on a database. H-BIM is expected to be a framework that not only visualizes recorded information in an easy-to-understand manner but also realizes the regular maintenance and management of cultural heritage, as with current buildings. Although there are cases where H-BIM is applied to modern buildings that match the IFC object definition, there are few cases that target archaeological sites that do not always match the IFC object definition.

Yasumuro created a digital archive that allows registration and accumulation of various types of information by assigning attribute information to objects such as murals and damaged areas as objects, targeting a Mastaba tomb in Egypt. (Yasumuro et al., 2016). This paper also approaches to establish an information model that organizes and accumulates past incomplete records and newly recorded information by linking them to each associated spot at the site of the Barbar Temple, where maintenance history since the excavation has not been recorded.

### 4D Modeling for Cultural Heritage

As a method of grasping the current state of archaeological sites, 4D modeling that adds the dimension of the time axis to the 3D model has attracted attention (Glowienka et al., 2017). Rodriguez and his colleagues (2018) used “Structure from Motion” (SfM) (Tomasi and Kanabe; 1992), which is a method of restoring the 3D shape from stored aerial photographs and photographs in order to analyze past natural disasters and landscapes changed in urban development. By comparing the restored 3D models, the secular changes in the photographs were confirmed three-dimensionally, and a more detailed analysis was performed.

At the Barbar Temple site, 3D reconstruction at the time of the excavation was attempted using photographs of the remains of the excavation. However, many of the photographs recorded at the excavation were taken close-up from the front of the archaeological site, the overlap between the photographs was small, and 3D reconstruction by SfM did not work. Furthermore, performing SfM by mixing current and past photos of the same place failed as no correspondence between feature points between images could be established. There is an alternative means for grasping a change over time, even for the case where 3D reconstruction is not applicable for available photo records. The authors proposed a visualization method to overlay the past photos onto the current scene and characterize the appearance differences over time (Mori et al. 2018). This approach showed in principle that the temporal difference in appearance could be me,asured as the actual displacement by virtually arranging and reading the scale of the actual scale for the transformation to be observed (see Fig. 2). However, it has only qualitatively visualized the change over time so that human eyes easily discriminate them, and the evaluation in terms of accuracy remains an issue. This paper shows a quantitative strategy to acquire a reasonable metric for secular changes in an archaeological site.

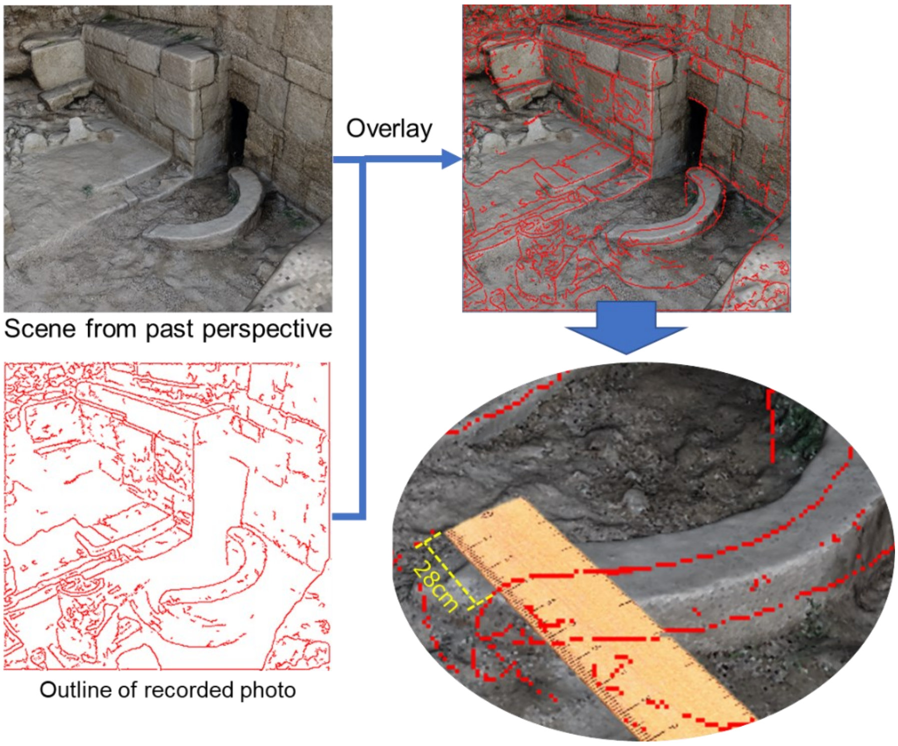



*Fig. 2. Previous Method (© N. Mori et al. [2018]).*

## METHOD

### Overview

In this study, to make the most of limited past recorded photographs and to grasp the difference from the present situation, the past recorded photographs were precisely superimposed on the current 3D shape data based on measurement. The displacement is measured by placing a virtual scale at the part where it is seen. This method quantitatively observes temporal changes that cannot be measured physically.

*Fig. 3* shows the system configuration of the proposed method. First, a 3D model of the actual size is generated by 3D measurement of the existing archaeological site to superimpose the past recorded photographs. In the coordinate system of this 3D model, the shooting position and orientation of the recorded photograph are estimated. The secular changes, such as the displacement of a stone position in a wall, can be easily observed at the comparison with an old photograph (Mori et al., 2018).

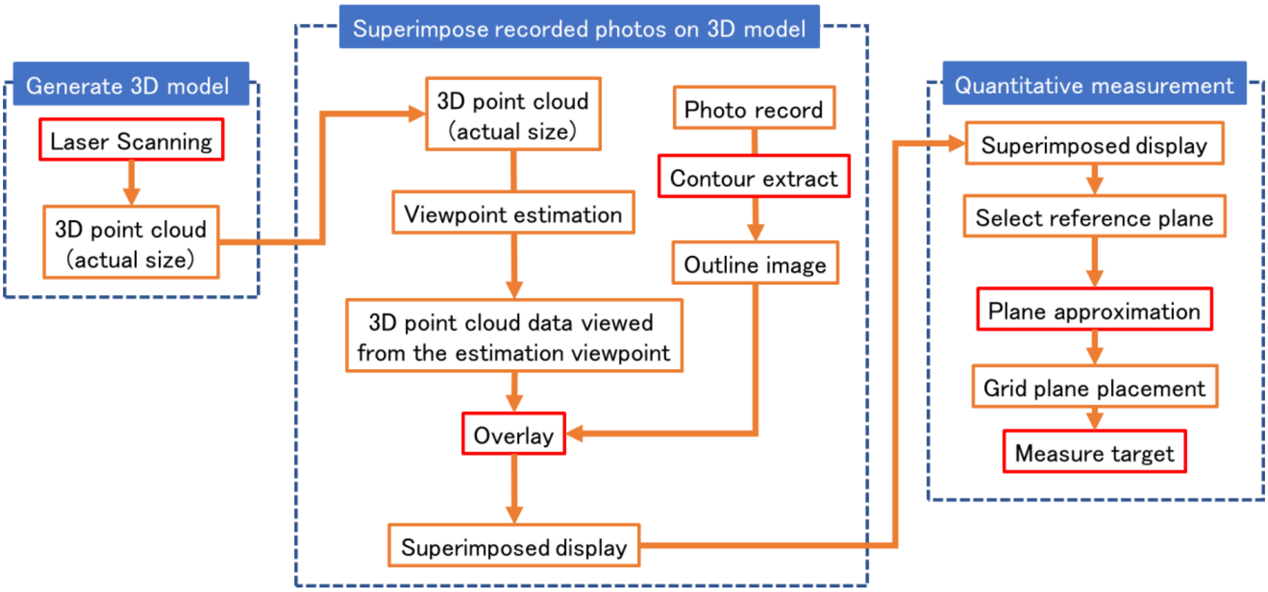



*Fig. 3. Process chain of the proposed method (© N. Mori et al.).*

To quantitatively observe the secular change in the real world, it is desirable to obtain three-dimensional information of the measurement target. An actual scale grid is used as a medium for giving 3D coordinates to the shape information of a photograph, which is 2D information. The secular changes, including crack sizes and stone displacements, can be investigated by arranging a gridded surface of actual size along the face of the stone. Our method uses a gridded surface that can measure the size of crack's progress and displacement of the target stone on the screen where the recorded photograph is superimposed on the current scene. By selecting two points, which are identified both ends of the size to be measured in the past and the present on the gridded surface, its displacement can be measured as a three-dimensional two-points distance.

**Implementation**

For estimating the shooting position and orientation of past recorded photographs, well-known Perspective-n-Point (PnP) problem (Hartley, 2003) is formulated and implemented and solver software libraries are available as well. To use this technique, it is necessary to prepare several pairs of 2D coordinates of the image and 3D coordinates of the photo image, and the internal parameters of the camera that captured the photo. In the recorded photographs of the Barbar Temple, information about the camera at the time of shooting is unknown. In this study, the pairs of the 2D coordinates of the recorded photo and the 3D coordinates of the current 3D model are manually associated in advance, and the initial values of the internal parameters such as focal length and image centre are given. The strategy of the proposed method is to change the internal parameters slightly so that the rendered 3D model overlaps the contour of the recorded photo while iteratively solving the PnP problem. The specific process for the refining of the solution of the PnP problem is shown in *Fig. 4*. Assuming the image center of the camera coincides with the optical axis, the lens distortion is assumed to be minimal, and the solution and rendering of the PnP problem are repeated while the focal length is slightly changed to obtain the best overlap display.

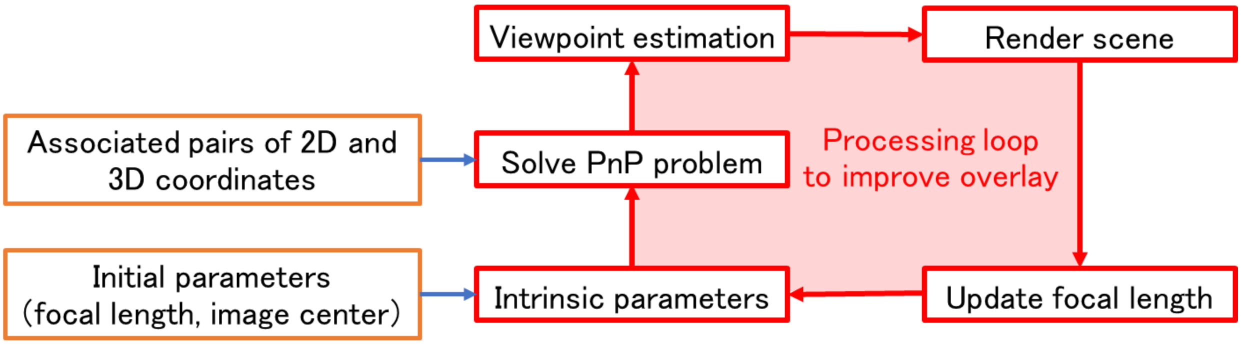



*Fig. 4. Iterative estimation flow (© N. Mori et al.).*

For the gridded surface placement, plane fitting by the least-squares method is performed. The plane used as the reference for gridded surface placement is a 3D point cloud included on the faces of the stones or part of the floor or wall of the structure. By solving the least-squares method for the point cloud in the sampled area, the normal of the approximated plane can be calculated. However, the least-squares method may suffer from a large error due to the influence of outliers in the sampled points. A robust way is to introduce Random Sample Consensus (RANSAC) (Fischler and Bolles, 1981), which removes outliers that have an adverse effect when using the least-squares method. The gridded surface is then arranged along with the reference point cloud by controlling the posture so that the normal of the grid matches the normal calculated by applying RANSAC. By selecting the point on the 3D model corresponding to the point on the contour line on the arranged grid by mouse picking, the displacement of the survey target can be measured in 3D space.

## Case study

### Barbar Temple

The proposed method is implemented on MS Visual Studio 2015 platform, and OpenCV was used in image processing for contour extraction and camera parameter estimation. As for graphical processing, OpenGL is used to display 3D data as well as 2D to 3D projection for mouse picking. This paper shows a case study to apply the method to the altar at the center of the Barbar Temple site. *Fig. 5* shows the processing flow up to the superimposed display. Comparing the past and the present state of the altar, some stones in the center of the altar pedestal cannot be confirmed in the present. Also, some stones surrounding the altar are moving or missing from their original position. In this case, the size of the missing stone on the right was measured. The 3D point cloud was acquired by measuring the surroundings of the pedestal from multiple positions using a laser scanner FARO Focus 3D X330, and aligning the scanned data by using the point cloud processing software, SCENE.

The Canny Edge Detector, which detects robust contours with few omissions in contour detection and false detection, was used to generate a contour image that was a key to confirm the difference between the past and the present. By giving transparency to the contours in the generated image, only the contours are superimposed on the scene that projected the 3D model by alpha blending during rendering. In terms of viewpoint estimation, seven identical feature points, such as stone corners and joints, were selected from the coordinates of the recorded photograph and the 3D model. For the internal parameters, the centre of the image was set to half of the vertical and horizontal pixels of the recorded photo, and the initial value of the focal length was set to 1.0 mm. The value of the focal length was updated by 0.1 mm until the outline of the photograph and the 3D data overlap precisely. Finally, an estimated viewpoint was adopted, so that minimizes the reprojection error between the feature points of the image and the corresponding points of the 3D model. When the superimposed display result is confirmed, it can be confirmed that both are precisely overlapped in the range in which the feature points are selected.

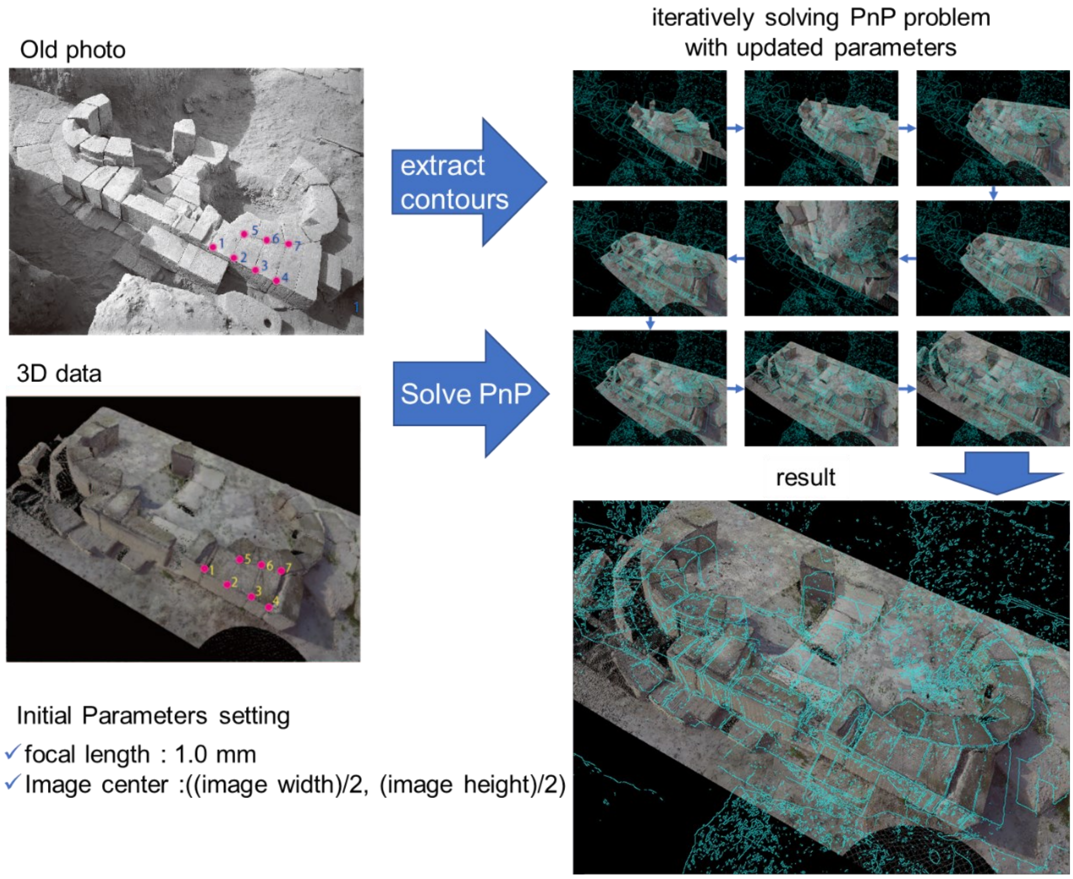
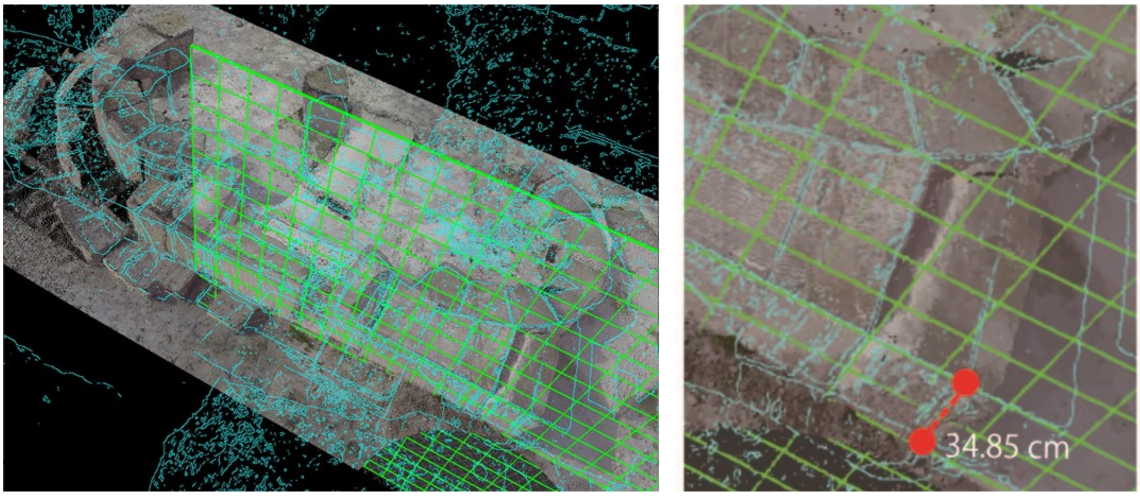
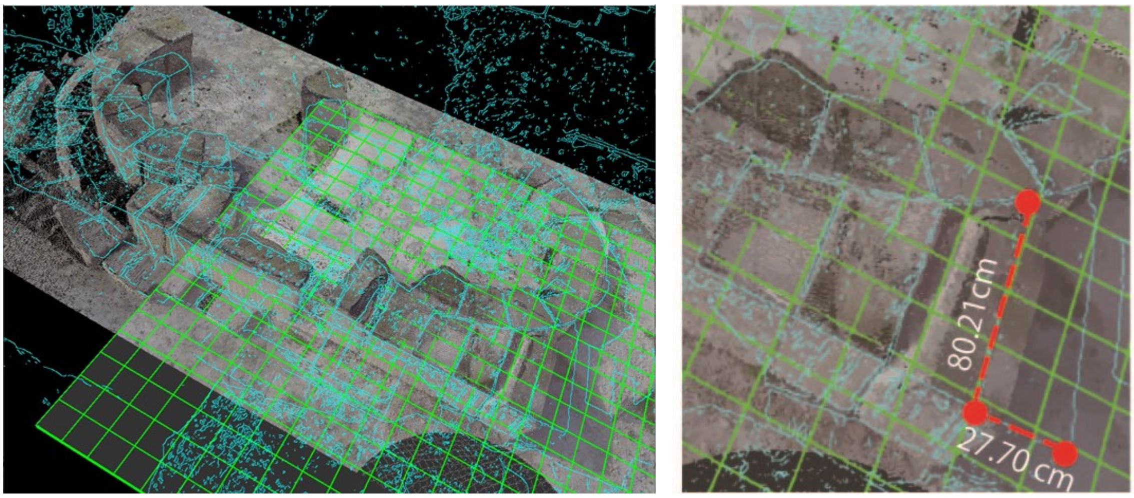



*Fig .5. Process flow of superimposed display screen generation (© N. Mori et al.).*

The right edge of the stone in the 3D model is correctly positioned next to the contour of the missing stone. In order to measure the width, height, and depth of the rightmost stone represented by the outline, the grid was arranged by plane approximation using the side and top surfaces of the stone of the offering table as sample ranges. *Fig. 6* shows the rendering scene when the grid is placed on the side, and the right side is an enlarged view of the left side. (a) shows when the grid is placed on the side, and (b) shows when the grid is placed on the top. The dimensions were measured based on the upper left corner of the stone. The red markers in *Fig. 6* represent the points to be measured. The results of each measurement were 27.70 cm in width, 34.85 cm in height, and 80.21 cm in depth.




*a) Grid placement on the side*




*b) Grid placement on the top*

*Fig. 6. Grid placement and measuring result (© N. Mori et al.).*

**Accuracy verification experiment**

The displacements quantified by the proposed method include some ambiguities, such as the distortion of the photograph as an image, the current 3D measurement error, and the viewpoint estimation error. Therefore, assuming the past and present changes, we prepared an experimental environment that grasped the grand truth value of the amount of displacement and verified the accuracy of the proposed method. The experiment was held at a rest space on the campus of Kansai University, which is made of stones like the Barbar Temple site. For preparing a grand truth of physical change in the structure, a platform with rails that moved exactly 5.20 cm was prepared, and brick, as a target object, is placed on the platform. First, we took an image that resembled a photograph taken in the past, moved the bricks based on aging, and integrated the 3D data measured from four viewpoints to obtain as the current record. Nikon COOLPIX L820 was used for photography, and the Focus 3D X330 was used for 3D measurement as conducted in the Barbar Temple site. The process from setting the grid surface to calculating the 3D distance was defined as one measurement trial, and the average of five measurement trials was used.

Fig. 7 shows the shooting position and orientation of the camera. In this experiment, the measurement target is the displacement of the upper left corner of the block. To analyze the effect of the camera direction on the proposed method, photographs were taken from the 15 different camera directions. The process from setting the grid surface to calculating the distance was defined as one measurement trial, and the average of five measurement trials was used. In Fig. 9, the horizontal axis is the angle between the camera direction and the displacement direction, and the vertical axis is the average error and standard deviation from the grand truth value in the measurement. The numbers shown on the horizontal axis correspond to the numbers shown in Fig. 8. The maximum error was 2.54 cm (see No. 14). In this measurement, the angle between the line of sight and the displacement direction was as narrow as 12.4 degrees, and the two points to be measured overlapped on the line of sight, making it challenging to obtain 3D coordinates. In other results, both the average error and the standard deviation were within an error of 2 mm.

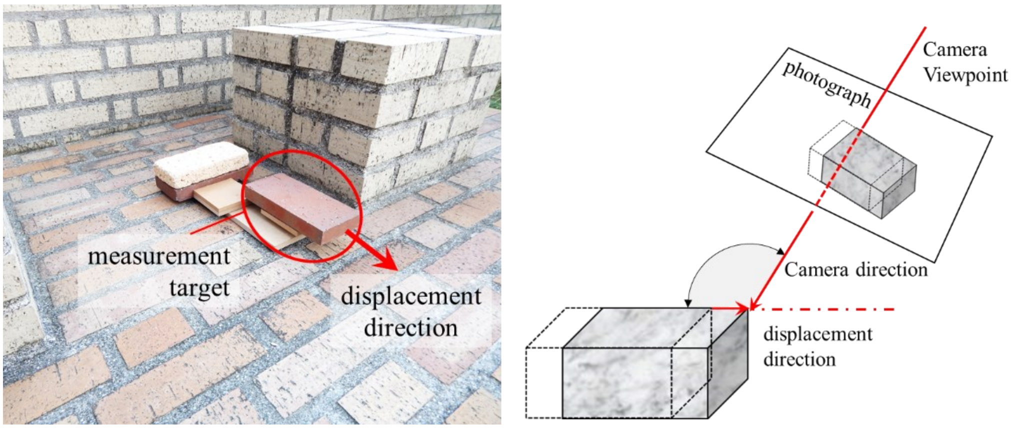



*Fig. 7. Camera position and orientation for the verification experiment (© N. Mori et al.).*

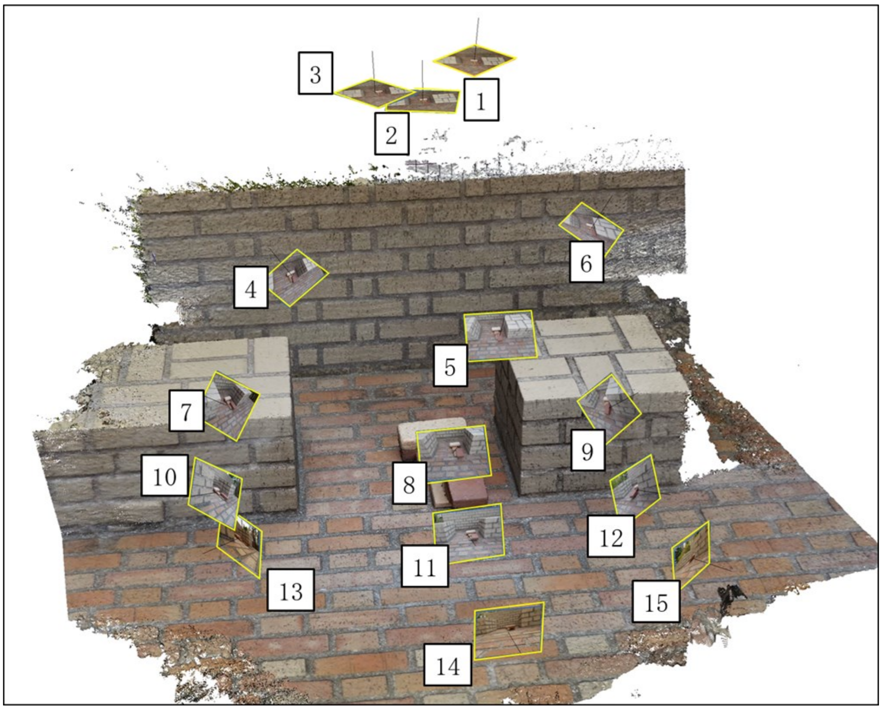



*Fig. 8. Camera position and orientation for the verification experiment.*

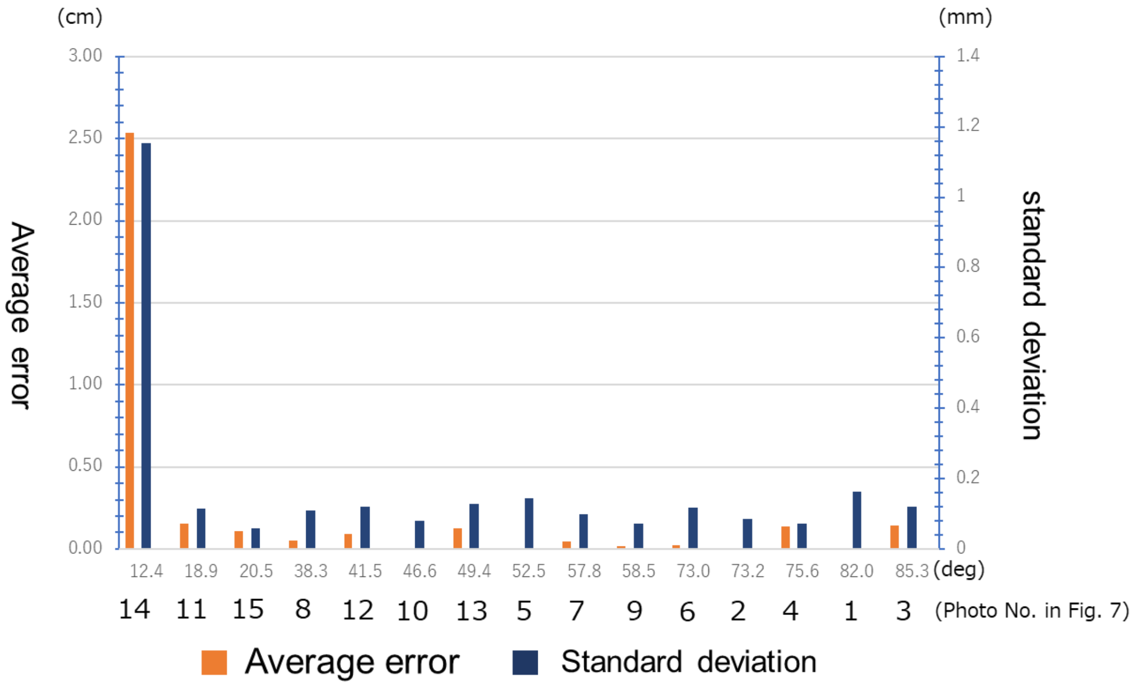



*Fig. 9. Average error and standard deviation during measurement of each photo (© N. Mori et al.).*

## Discussion

The laser scanner used in this experiment has a maximum ambiguity of about 2.0 mm when measuring a wall 10 m distant. The error in alignment for integrating scanned data was 1.7 mm. The angle between the displacement direction to be measured and the line of sight of the photo applied at the Barbar Temple was 48.9 degrees. In the case study mentioned above, the line-of-sight angle is within the effective range verified in this experiment, so it is expected that the same accuracy was obtained. Similar effects can be expected by applying this method in various places in the field. Nevertheless, it is vital to select a reliable and sufficient number of reference points. Therefore, evaluating the reprojection error due to the PnP problem's solution is necessary each time.

As a proposal of archaeological information modelling based on 3D measurement, recorded photos can be integrated into the current 3D space, and both maintenance and structural information can be managed in a relational database. As a user-interface to this database, data browsing and data updating functionalities can also be integrated on a Web-based system Fig. 10 and Fig. 11.

## Conclusion

In this study, by superimposing photographs taken in the past on the current 3D model, it was possible to confirm changes in the appearance of structures over several decades from the excavation to the present. By applying this method to archaeological sites where the state at the time of the excavation cannot be three-dimensionally restored, the secular change could be shown in an easy-to-understand manner. In addition, it was possible to reconstruct the local but two-dimensional shape information of a photograph as a three-dimensional shape by combining it with a real-sized virtual space that reproduced the scene.

Our future work is to measure the variety of secular differences not only simple displacements but also curvature and volumetric changes, such as appeared on stone walls. Also, our project plans to extend the implementation of the information model toward Heritage-BIM by incorporating a mechanism to directly define the objects not only in photos but also in arbitrary regions on the 3D surface of the measured structure.

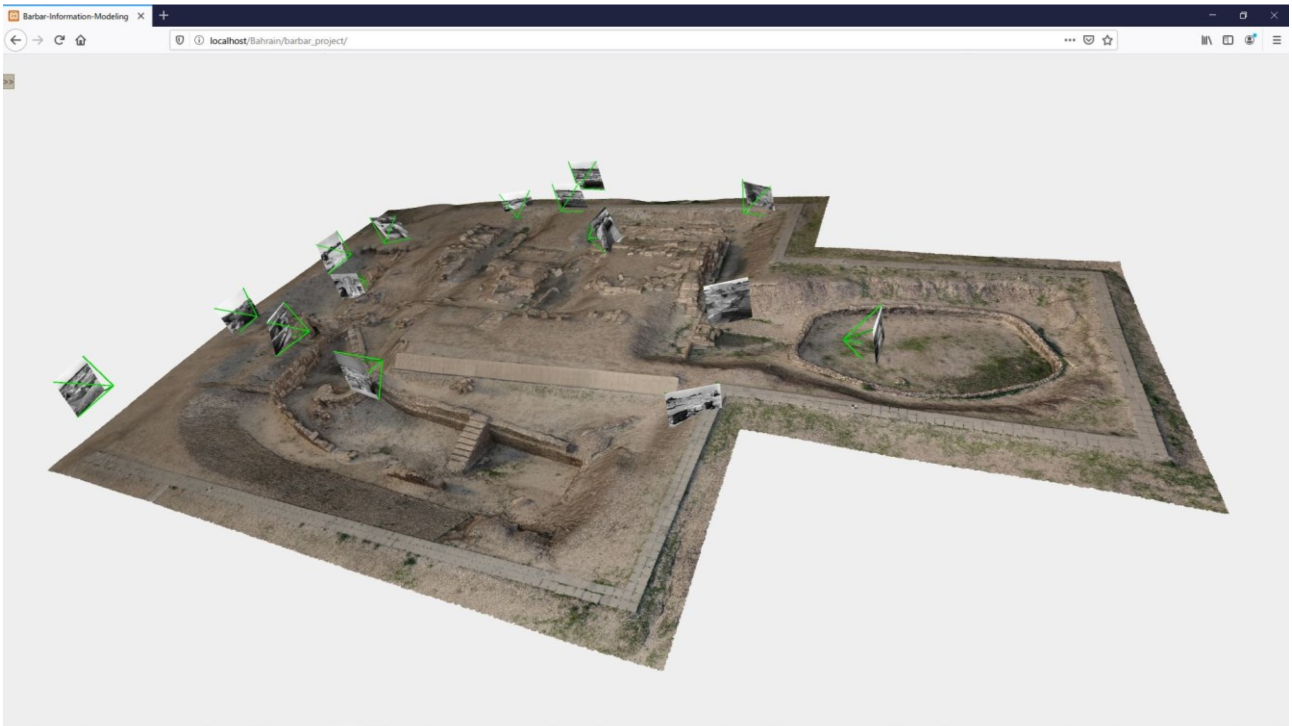



*Fig. 10. Survey record visualization interface (© N. Mori et al.).*

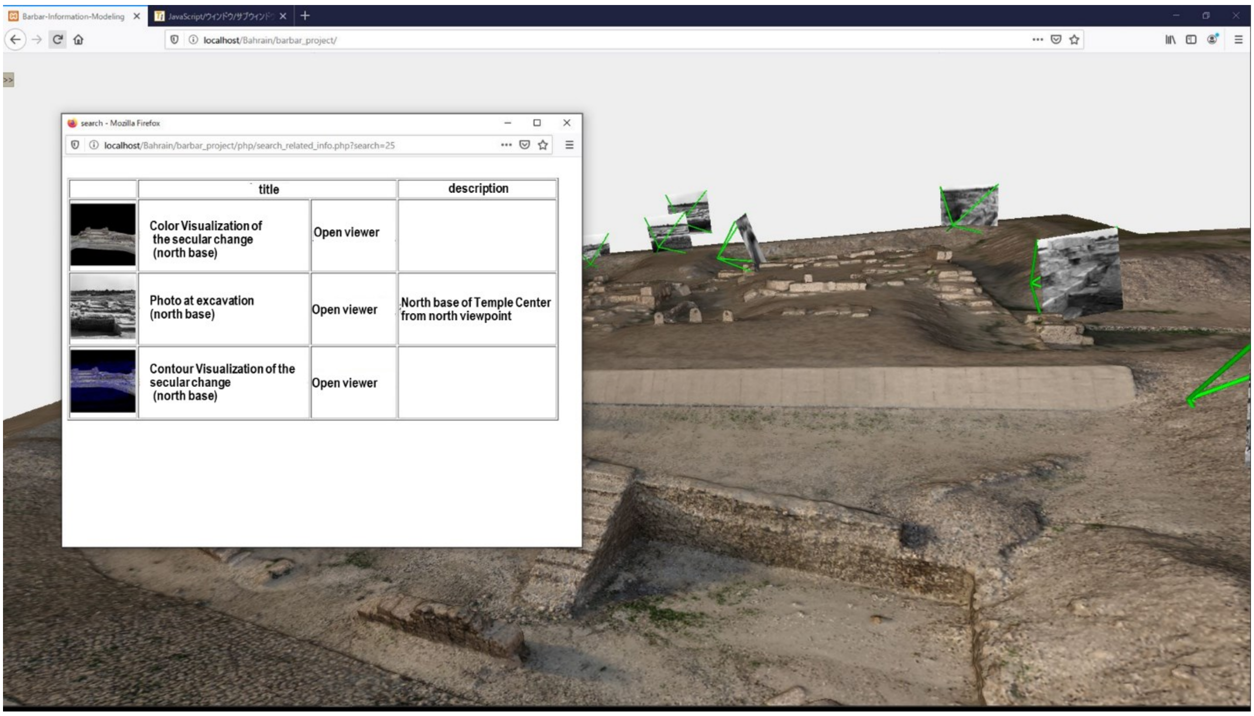



*Fig. 11. Pop-up of related information (© N. Mori et al.).*

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# Pathology detection for HBIM application on a Byzantine church in Axos village in Crete, Greece

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**Abstract:** The introduction of digital photogrammetry techniques in recent years regarding monumental structures brought about significant changes in their survey and representation. Apart from the obvious benefit in geometric accuracy and the visual qualitative information, useful for archaeologists and architects, deliverables can also be used by a number of experts, like civil engineers and restorers, having been processed accordingly, aiming in a future usage in BIM technology. Building Information Modeling (BIM) is the most modern, effective and functional technology applied in the AEC field nowadays, since it has numerous possibilities in combining data of multiple kinds in a readable format accessible by different scientists and experts. Research and discussion on Heritage BIM, an effort of describing the application of BIM technology in historic buildings, is being carried out at an increasing scale lately, as most countries realise that preservation of cultural heritage is closely related to the future and prosperity of humanity. By its definition BIM seems to be ideal for issues regarding existing structures and monuments in particular, because it has the ability to integrate different type of data, from architectural design to historical and structural information, as well as pathology and intervention techniques. The paper presents pathology detection using photogrammetry, the documentation and classification of existing damages on a byzantine church on the island of Crete in Greece, providing the possibility of implementing the selected data to the HBIM model of the monument. The specific monument is selected due to its significant value frescos and a method of pathology diagnosis using photogrammetric tools will be analysed.

***Keywords:*** *Byzantine Architecture—Photogrammetry—Laser Scanning—Cultural Heritage—HBIM*

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## Introduction

Building Information Modeling (BIM) is a revolutionary technology that is characterized as the opportunity of the AEC (architecture, engineering and construction) industry to move to the digital era and improve the collaboration amongst the partners of this industry by exploiting Information and Communications Technologies (ICT) (Eastman, 2008). BIM provides automation capabilities for more integrated communication, data exchange and sharing between project actors within a virtual 3D environment (Gu and London, 2010). Implementing Building Information Modelling may be an approach to enhancing collaboration, attempting to reduce fragmentation. BIM connects different tools as a repository framework and allows queries on building conditions, time management, and cost estimation to plan effective and sustainable interventions (Bruno et al., 2018). In a relatively limited time, the implementation of BIM has developed from a 3D model (basic space dimensions) to a 4D (time) and 5D (cost) model, giving the ability to stakeholders to have access to and control not only geometric, but also non-geometric information, contributing to a more secure and cost-effective decision-making. The designed virtual models are directly linked with databases of all information in order to achieve the best possible management in the buildings' life cycle, from the design phase, construction, management, maintenance to its demolition. Using shared neutral exchange formats, like Industry Foundation Classes (IFC) and cityGML (city Geographic Markup Language) all data and information can be exported and used accordingly by all parties involved (O'Keeffe and Bosché, 2015). Therefore, the utilization of BIM as a tool for all relative stakeholders (scientists from multidisciplinary fields, construction, and real estate companies etc) is going to grow bigger. Already, many countries such as UK have introduced BIM technology as an obligatory construction process for public buildings, due to its regulatory requirements (Ewart and Zuecco, 2019).

Acknowledging the numerous applications and possibilities of BIM technology to combine various data in a single file, accessible to different scientists and experts, researchers have been trying lately to apply BIM on buildings of historic value (Murphy, 2012). Heritage or Historic Building Information Modelling (HBIM) is a new approach to create intelligent three-dimensional models and databases of historic buildings that integrate information and data, attributing in processing architectural designs (Maxwell, 2016), static analysis (Castellazzi et al., 2015), seismic vulnerability (Mondello et al., 2019), pathology (Dore et al., 2015) (Turco et al., 2017), ICT computing, geomatics, cultural heritage documentation (García et al., 2018), architectural intervention techniques (Oreni, 2013) and maintenance practice. However, despite the aforementioned pros that BIM can offer, it still remains in a research phase, with limited use by authorities in charge of conservation (Fai et al., 2011) (Fregonese et al., 2017). The slow integration and implementation of BIM in the field of restoration of monuments could be attributed mainly to the variety and complexity of heritage assets (García-Valldecabres et al., 2016), as well as to the lack of precise regulations and guidelines (Arayici and Tah, 2007, Volk et al., 2014).

The application of BIM in a structure of cultural heritage (CH) comprises the following steps (scan-to BIM process): a) Historic-architectural-structural survey b) Data capture c) Data Processing d) Object recognition (semantics) e) BIM Modeling (Volk et al., 2014). Each of these steps is still under development, underlining that the method followed every time is customizable by the building/site and its special specifications.

The analytical and theoretical research regarding historic data is of high importance when dealing with a CH building, contributing to right decision making by the researchers in following the best suitable survey technique, having studied structure's construction phases and changes through time, in order to limit the time of the work on site.

In a digital documentation and 3D modelling project, the basic goal is to have an accurate and photo-realistic digital representation of the structure, to support activities like investigation and interpretation as well as for educational or cultural benefits. Accurate data capturing and survey techniques is usually done using photogrammetry and/or Laser scanning (Remondino and Rizzi, 2010). The choice of the best approach depends on required accuracy, object dimensions, location constraints, system's portability and usability, surface characteristics, working team experience, project's budget, final goal, etc (Aveta et al., 2017). Today RPAS (Remotely Piloted Aircraft System) and TLS (Terrestrial Laser Scanning) survey can produce high quality point cloud and 3D model in archaeological sites, in limited time and with satisfying metric accuracy.

Data processing, unlike capturing, is a time-consuming, complex procedure that requires a lot of working hours by specialists, to produce an accurate 3D model of the scanned building. During processing, point cloud data that derives from images (photogrammetry) or laser is registered, aligned and merged into the same coordinate system. Manipulation of the scanned data includes noise removal and cleaning point cloud from irrelevant information. The procedure, according to the size of the structure, the desired accuracy and further requirements, may take significant computing time, due to large volume of data and limitations on computing performance. The point cloud data is finally converted in forms that can be used by CAD software for minimising the necessary disk space and computers' high-end specifications.

Object recognition and BIM modelling is the last sector where all gathered data is classified and integrated to a 3D digital description of the structure, its site and related geographic information system (GIS) context. During this process, the building is comprised with attributes defining the properties of each object as well as their relationships, differentiating the process from CAD, transforming objects from graphical entities (lines, arcs, circles) to semantic elements (walls, beams, domes, etc). The final model comprises all information in one repository in an integrated data environment, ensuring consistency, accuracy and accessibility of data. Nevertheless, semantic classification is under scientific research, as all CH structures, even buildings of the same period or type, have special features that make them unique. Therefore, a strict classification under special regulations and guidelines is not possible to be set, since each case study is different from the other, demanding a different approach and method of analysis. The standard classification most BIM software use in managing architectural elements is unable to fulfil CH needs, because of the complexity of historical assets and their unique architectural, structural, and artistic character, which requires a multi-disciplinary approach, involving different scientists and a specialised way of working. Research work is done towards usability and flexibility in semantic data management, in order to satisfy the case-specific requirements and meet the needs of all parties involved.

In this paper a research case of documentation of structural pathology for HBIM implementation on the byzantine church St. Ioannis Prodromos in Crete, Greece is presented, analysing the process of historical analysis, data capture using laser scanning and photogrammetric tools and documentation, proposing a method for pathology diagnosis and classification to be used in an HBIM application in the future.

## Methodology

### Historical analysis – documentation

The church of St. Ioannis Prodromos is located in Crete, at Psiloritis mountain, in Axos village. Axos is located to the municipality of Mylopotamos, in Rethymno's county, 46 km away from the city of Rethymno and 48 km from Heraklion, at an altitude of 500 m, approximately. The Church is located approximately at 150 m. easter of the current settlement of Axos on a hill. The surrounding area is listed as a protected historical location by the Hellenic Ministry of Culture, whereas St. Ioannis is the most well-preserved byzantine church in the settlement of Axos. Although a written proof of chronological reference has not been found yet, according to Em. Borboudakis, archaeologist and ex Director of Byzantine Ephorate in Crete, based on his study of the internal frescos, the church was probably built in the first half of 15$^{th}$ century.

### Typology – architectural analysis

St. Ioannis Prodromos is a single-aisle arched church with two internal stone arcs for additional structural support and a duo-pitched roof with byzantine tiles which is not the original, since the roof of the temple was replaced in the '90s (Fig. 1). The width of the church externally is 5.15 m and its length, up to the arch of the sanctuary, is 8.90 m and with the arch is 10 m (Fig. 1). The width of its interior is 3,62 m. Sanctuary's arch was built on the remains of an older church, which today is preserved at the level of its foundation, 0.20 m over the ground surface. One of the most interesting aspects of this church is a byzantine tile (sleeper), which can be found at the right and left side of the sanctuary's arch at a height of 2.46 m, which has been placed inside the stone structure and was used as a sink, for the elimination of water and moisture, trapped between the roof and the masonry.

In the interior, area consists of the the main temple on the west side and the Sanctuary. Entrance is located on the west façade, having a stone architectural part as a doorstep, probably re-used from a nearby ancient monument of dimensions 1.10 × 0.50 m. On the perimeter of the main temple there is a stone-built desk covered with concrete. Church is fully painted with frescos representing numerous instances from St. Ioannis' life, as well as other Christian-Orthodox ceremonial subjects and Saints images. One of the most interesting and important aspects of the church besides its frescoes is the mosaic found on the southeastern side of the floor. This element was significant to the whole study, as it helped in the dating procedure of the monument. The remains of the mosaic, after being cleaned, were imprinted with millimeter accuracy, giving the possibility, after an extensive study of its themes and style, to identify that it was created in the byzantine period.

*Fig. 1. SouthWestern view of St Ioannis Prodromos in Axos, Crete.*

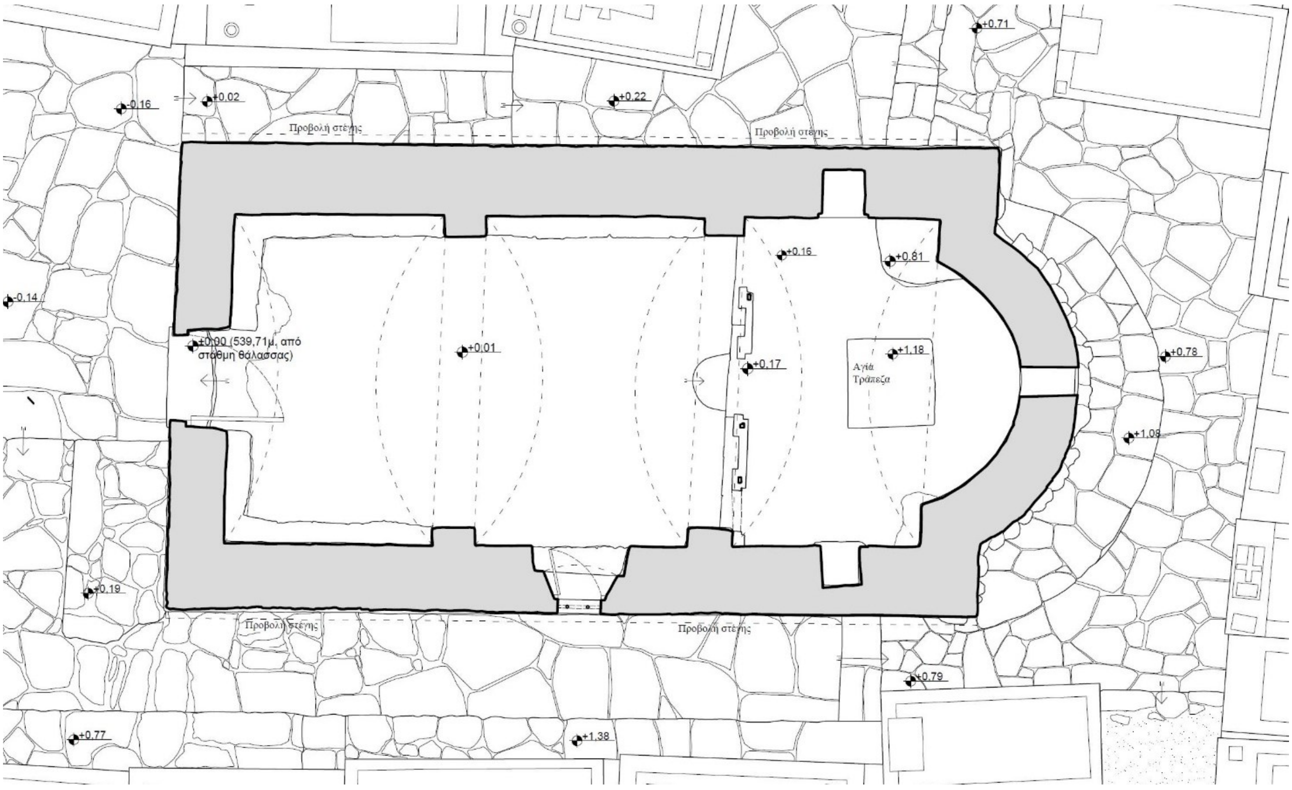


*Fig. 2. Floor plan of St Ioannis Prodromos in Axos, Crete.*

## Pathology diagnosis using laser scanning and photogrammetry optimization and filtering

### On site survey – laser scanning- TLS data acquisition

The architectural survey was executed by using Faro's 3D Multisensor Focus Laser Scanner. Planar and spherical targets were used to contribute and control the point cloud registration. Two planar targets were positioned on each wall (for a total of 8 targets) and ten spherical targets were placed distributed so as every scan included at least 3 of them for better results. The planar targets, measured with a total station, may have the dual role of helping point clouds registration process and georeferenced the data in the local reference system (Lo Brutto et al., 2017). The number of positions, and therefore the scans, depend on each space or object and their selection is made in order to avoid shadows and hidden spots. If there are obstacles or overlapping objects, the number of scans must be increased, so that under different angles would be scanned each item, and included in the final model. In this particular case, the accuracy was determined at 6,15 mm and included four repetitions per scan (England, 2018). Finally, 9 scans were produced and the whole procedure was carried out, allowing the engineers to gather all data needed for a restoration study, on a single working day. After scanning process, laser scanner took photos and started the colorization of the scanned points, using the built-in self-adjusting color digital camera, capable of producing high-resolution panoramic images of up to 70 megapixels. The optical beam of the camera is coaxial to the laser beam; thus, scanner can photograph simultaneously by scanning the object and attaches it to the cloud points of real chromatic texture (Aveta et al., 2017). Data was stored on an SD memory card, so when the field tasks were completed, it was transferred to the workstation.

### Point cloud optimization – mesh modelling

Faro Scene was used for point cloud optimization, smoothing and filtering, as well as creation of orthophotos, while highly accurate architectural designs were made using Bentley Pointools View, saving a significant amount of effort and time comparing it to traditional methods. Although the initial intention of the study included using Revit for the whole project, all architectural designs were finally made in AutoCAD, because the highest possible level of accuracy was needed as far as geometry was concerned. A model in Revit Architecture was created based on AutoCAD designs on a second phase of the project, as described on the following chapter. The final 3D point cloud model, which is comprised of seven hundred and eighty (780) million points, had the accuracy needed for further processing and design drawing. The final product allows the engineer to have all possible aspects and views of the monument, like sections and axonometric models, very useful for the architectural, structural and conservation studies (Fig. 3).

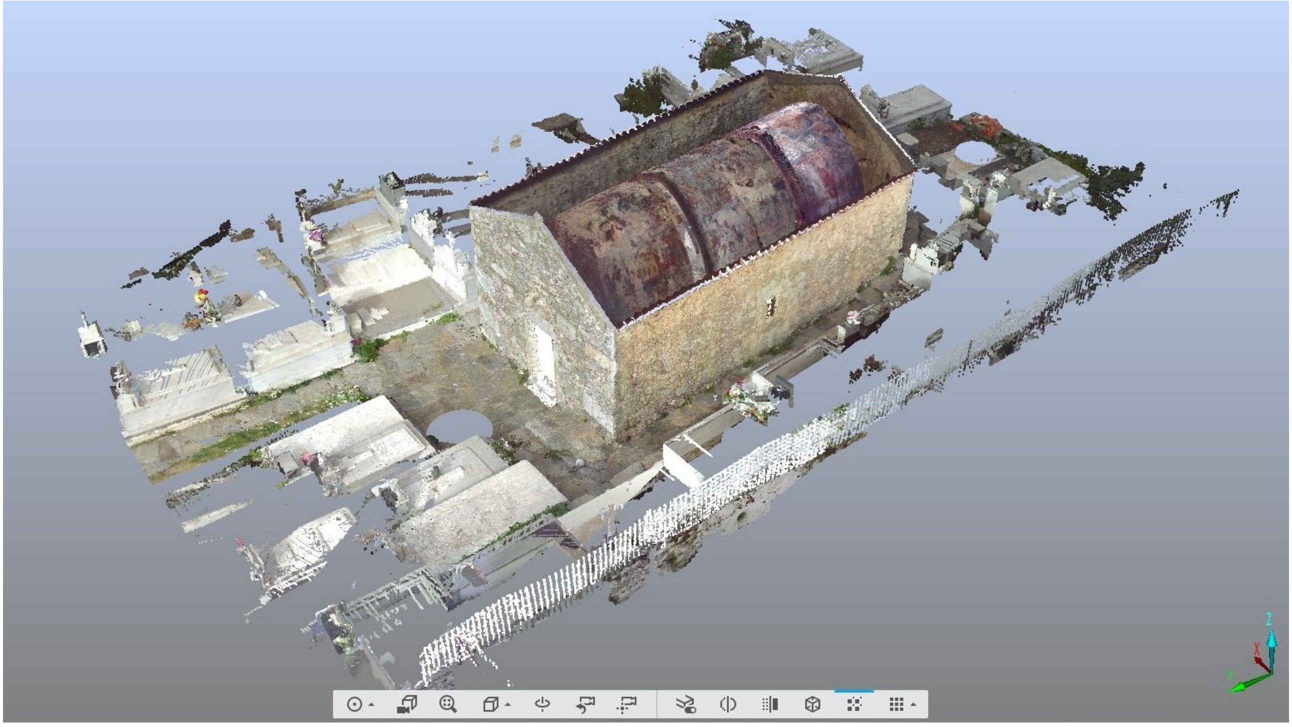

*Fig. 3. 3D Digital model- Pointcloud – Axonometric view of the church (© Authors).*

**Pathology diagnosis**

The data from the on-site work permitted the detailed study of the monument in the office. The church's masonry is covered with thin lime-based plaster, while on several areas there have been more recent cement interventions both in mortars and in plaster. Aesthetic problems are caused by large amounts of concrete mortar, which have been used at the end of the pediment for reasons of roof waterproofing.

In-situ research revealed that the church was built on the remains of an older Christian church and has undergone some minor interventions throughout its life history. However, nowadays it is facing various problems regarding the deterioration of materials i.e. due to environmental causes (humidity) and structural integrity due to damages caused by earthquakes taking place in the area. After evaluating all information gathered and having studied monuments' typology and special characteristics, research focused on documenting two different categories of pathology issues: *structural* and *non-structural* (aesthetic) ones.

Pathology diagnosis for structural engineers demanded the highest possible level of accuracy regarding cracks, differences in the shape of structural elements, severe humidity issues that affect stability, etc. Therefore, a methodology using digital processing of selected orthophotos was followed. This technique was chosen as the best applicable one since the whole church was covered with frescos inside, making existing cracks difficult to mark and notice. This phenomenon was worsened by the high level of humidity which had created large blackish areas on the facades. Digital processing including removal of the RGB filters and controlling of orthophotos' level of intensity was carried out in all interior surfaces, making frescos disappear and cracks appear clearly on the walls and arches (Fig. 4, Fig. 5). Architectural designs of pathology were finally made in AutoCAD using Bentley Point Tools for numerous sections, because the highest possible level of accuracy was needed as far as geometry was concerned. This methodology allows civil engineers to have all the necessary data concerning structural problems and by combining them to their structural analysis to come to helpful conclusions and suggestions regarding measures for restoration and strengthening of the monument, having spent a limited time on the specific site. Taking into account that this data can be used by public officers of e.g., a Ministry or a Municipality, whose presence all over the country to inspect all monuments is almost impossible, this technique could contribute in having immediate results and estimation regarding integrity of each structure.

*Fig. 4. Orthophoto of the north facade of St Ioannis Prodromos Church in Axos.*

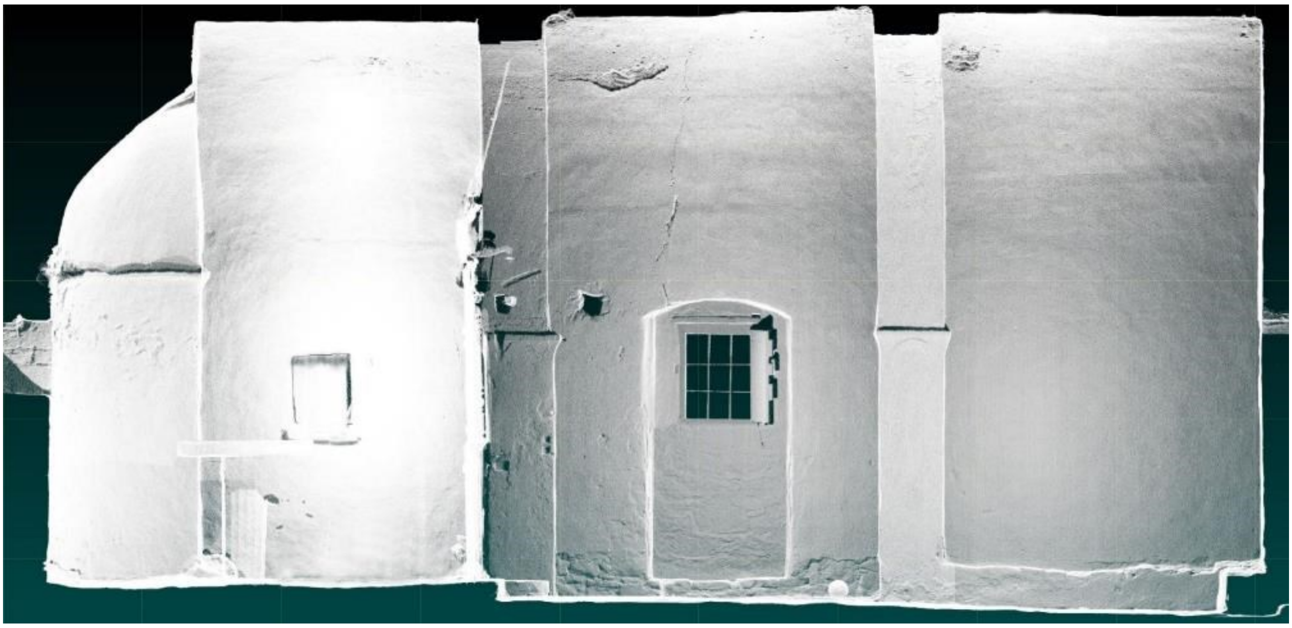

*Fig. 5. Orthophoto of the north facade of St Ioannis Prodromos Church in Axos, without RGB filters, used for crack detection.*

At parallel, conservators used orthophotos and digital processing in order to document frescoes pathology (non-structural problems). Since their significance was considered of high importance for the restorers, a more specialised approach was followed, that required detailed drawings for the frescoes of each façade, where pathology issues were documented in full detail (Fig. 6).

*a* *b*

*Fig. 6. West internal façade a) Orthophoto b) AutoCAD drawing with pathology mapping.*

**Pathology documentation and classification**

Final documentation on pathology was implemented after evaluating all characteristics of the monument, leading to the creation of a database in Microsoft Excel, to be used by a data management tool in any of the most known commercial BIM applications (Bruno and Roncella, 2019). Each structural and non-structural member of the model was classified according to this methodology, having the ability to add all relevant photos, sketches, historical data for every one of them to the database.

Focusing on pathology, a distinct separation on structural and non-structural problems was implemented. After a thorough evaluation by both architects and civil engineers, all cases were classified in 16 categories, regarding both serious structural problems, like cracks and collapsed areas, as well as less important ones, but still significant, like humidity or missing plaster (Fig. 7) (Turco et al., 2017), (Malinverni et al., 2019). Well-preserved areas were also marked, in order for engineers to be able to have a first but still established opinion about structures' current condition, allowing best possible decision-making by restorers and helping eliminate mistakes regarding the cost and planning of restoration works. Documentation was made on the architectural designs, marking each area with its diagnosed pathology, so as to be attributed visually to the elements of the 3D model.

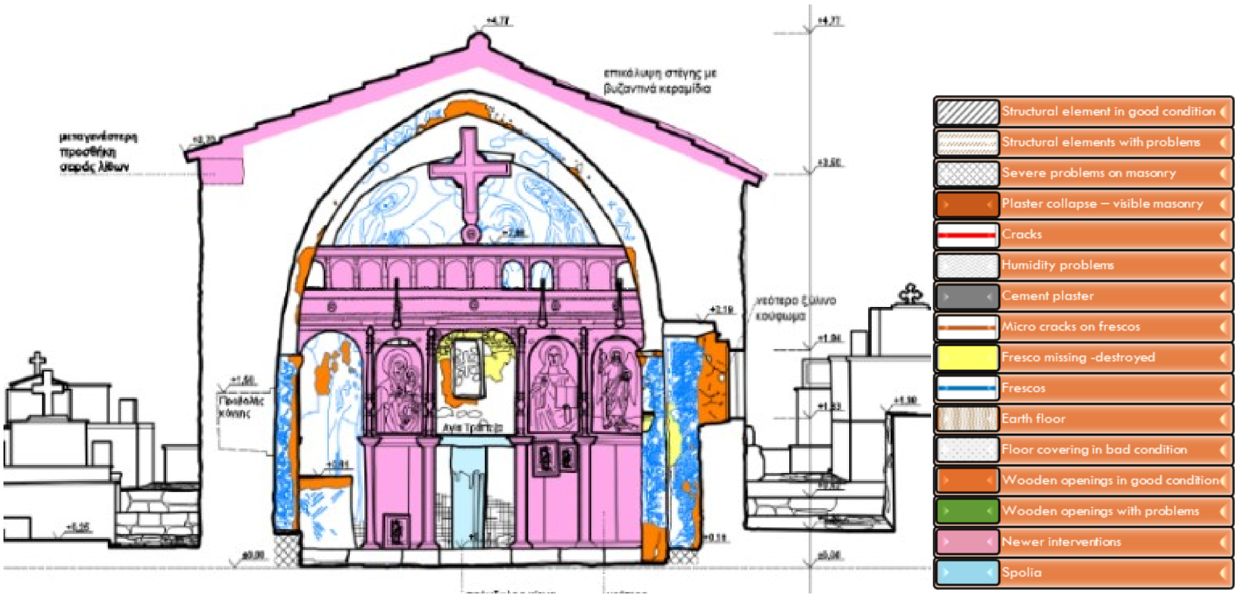


*Fig. 7. Structural pathology documentation.*

In a second phase of the project, a model in Revit 2021 Architecture was created, using all existing designs and information (Fig. 8a, b). Wall and floor architectural elements were used for the creation of masonry, vault structures and grounding area, while the materials of the Revit 2021 library were used (Fig. 8c, d), awaiting the analysis of the mechanical characteristics for further expansion of the attributes. The filling material between the vault and tiles was modelled as well, adding to the constructional accuracy of the model. All information regarding pathology, photos, pathology designs, etc, are added as pictures linked to each façade, while the excel database is being combined to the Revit model.

Further planning of this on-going project, includes adding numerical data on the model, such as crack width and other characteristics (position, cause of appearance, etc) linked to the structural model of the monument which has been created in SAP (Fig. 9) and locates the «sensitive»—more vulnerable areas, for structural engineers to be able to assess the further deterioration of the construction and propose on time the best measures necessary in case of emergency or danger of collapse.

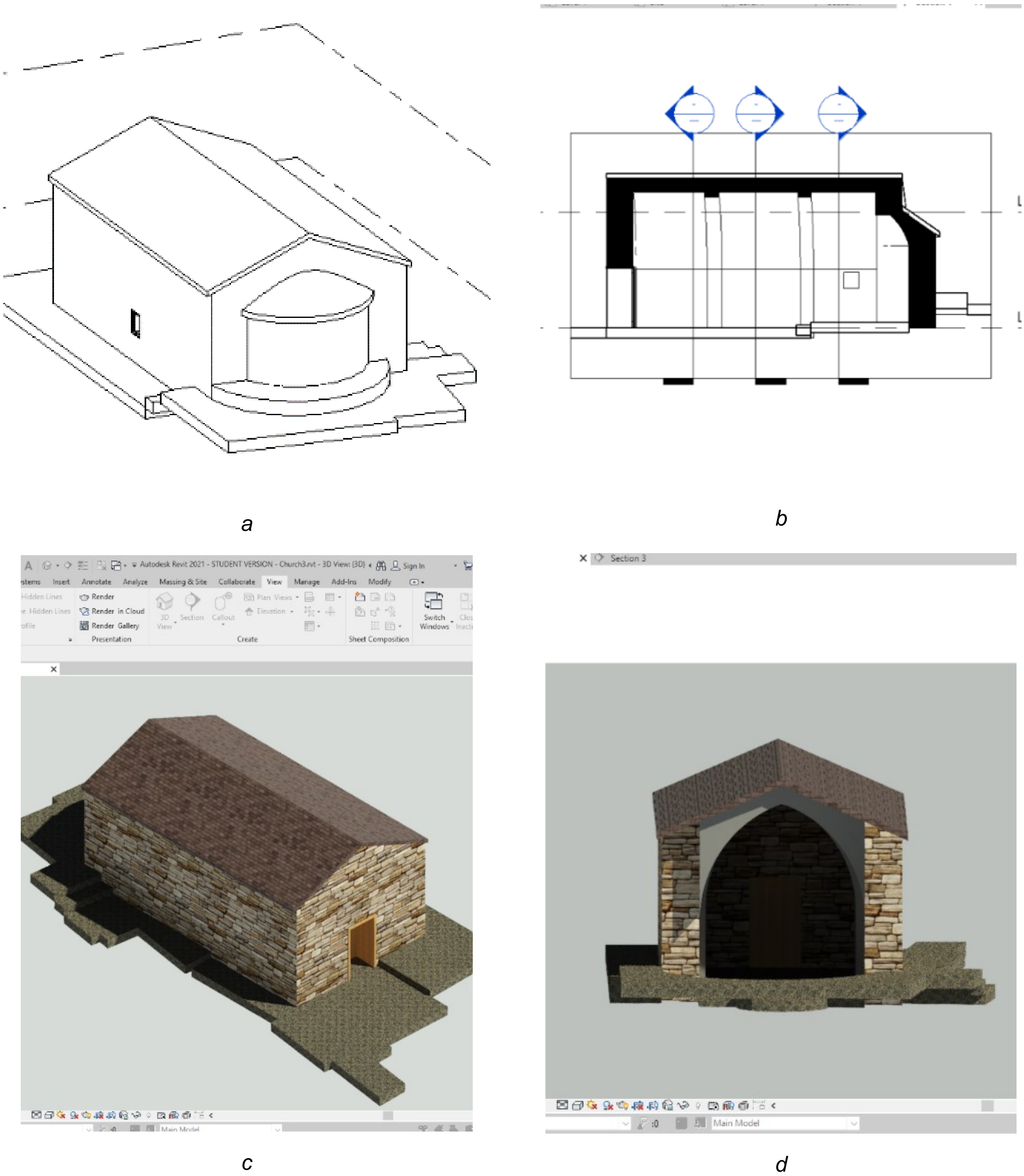


*Fig. 8. Model of St Ioannis in Revit 2021 Architecture.a) 3D SE view b) Cross section c) Photorealistic NW view d) Cross section where different material is shown.*

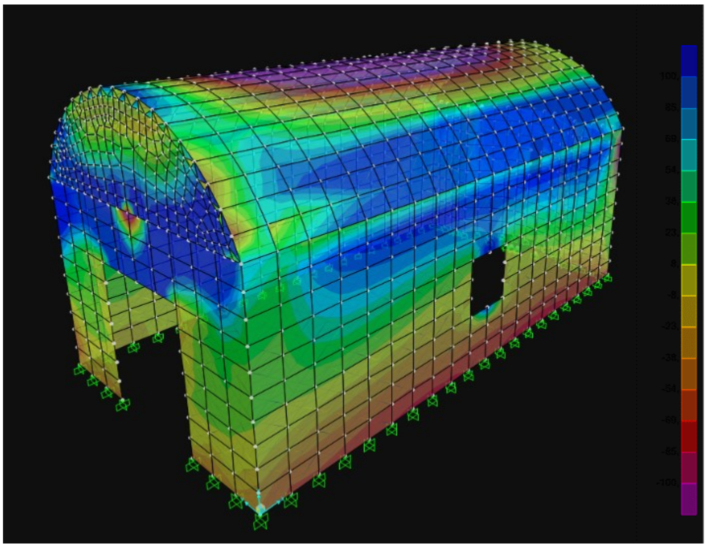

*Fig. 9. Finite element model in SAP2000.*

Non-structural (aesthetic) problems focused on frescoes, where façades were separated in frames for every form, linked to a list with the name of the Saint or the Christian expression that can be further expanded using semantics regarding orthodox icon themes. Pathology was classified in 16 categories, regarding only the problematic areas and including issues like micro cracking, missing colours, biological damage, etc (Fig. 10). It is important to note that in this case a close collaboration with experienced conservators was necessary, for a full and thorough documentation, that could save both time and money in the restoration process.

This methodology allows scientists in the field of cultural heritage restoration to document accurately a historic building and collect pathology information that can be used on an HBIM central repository, underlining that the use of Excel database that was followed in this methodology can be expanded in the future by combining Linked Open Data solutions and IFC technology along with the Revit model.

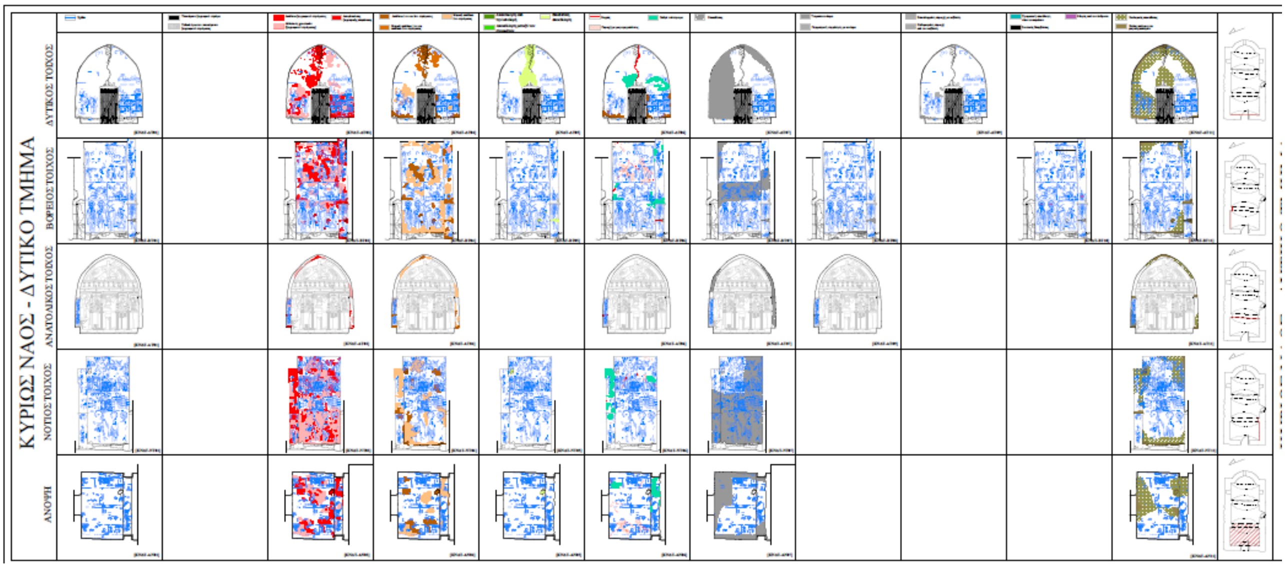


*Fig. 10. Frescoes pathology documentation.*

### Semantics

In the field of CH, the integration of semantic data with 3D models using BIM technologies (Scianna et al., 2014) allows to preserve an exhaustive level of information of the cultural good available for all stakeholders. In this particular case, a semantic classification was implemented, trying to categorise every structural and architectural member, according to VRA Core 4.0 standards and using controlled vocabulary databases, especially the Getty vocabulary program (Fig. 11).

| WORK | | | | | |
|---|---|---|---|---|---|
| VRA Core Element | XML Element | XML Child Element | XML Attribute | XML Child Element | DATA |
| - | - | - | - | - | - |
| TITLE | title | | | | Church of St Ioannis Prodromos in Axos |
| - | | | type | | cited |
| WORK TYPE | worktype | | | | churches (buildings) |
| | | | vocab | | AAT |
| | | | refid | | 300007466 |
| CULTURAL CONTEXT | culturalContext | | | | unknownGreek Orthodox |
| | | | vocab | | ULAN |
| | | | refid | | 500355123 |
| DATE | date | | | | 15th century |
| | | | type | | creation |
| | | | latestDate | | 1450 |
| DESCRIPTION | description | | | | Church of St. Prodromos is the best well-preserved byzantine church in the settlement of Axos. It is a single-aisled arched church with two internal stone arcs for additional structural support and a duo - pitched roof with byzantine tiles |
| LOCATION | | | | | |
| | location | | | | Crete |
| | | type | | | administrative |
| | | | name | | Crete |
| | | | | type | inhabited place |
| | | | | vocab | TGN |
| | | | | refid | 7012056 |
| | location | | | | Axos |
| | | type | | | administrative |
| | | | name | | Axos |
| | | | | type | inhabited place |
| | | | | vocab | TGN |
| | | | | refid | 7233983 |
| MATERIAL | | | | | |
| | material | | | | masonry |
| | | | type | | medium |

*Fig. 11. Semantic classification*

## Conclusions

In this paper, a method of pathology detection using photogrammetry and an attempt of documentation of structural and non-structural pathology of a byzantine church, was presented. Data processing required a multidisciplinary approach and was highly demanding. Documentation was made using human intervention on architectural designs, providing the possibility of implementing the selected data to the HBIM model of the monument. The proposed methodology starting from historical analysis, 3D data survey, documentation and classification of pathology can be used in creating the necessary parameters in a model of a byzantine monument in an HBIM platform, having the possibility to be expanded and enriched following the example of worldwide development in semantic data management for such buildings, like the MonArch[1] project or the Baureka[2] platform. Nevertheless, the acquired data can be very useful in the future restoration studies as well as in the actual working phase, saving a significant amount of time and money, by offering accurate and detailed information.

In addition, the methodology proposed for crack detection by digital processing of orthophotos can be used not only on pathology survey but also on the monitoring of the structure through time, arriving at significant conclusions about the gradual deterioration of a building and the necessity of urgent interventions. This way, researchers could reach to accurate results, having spent the minimum possible time on site and contribute to the HBIM documentation of cultural heritage.

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# Session:
# PhD/Master Session 2019

Martina POLIG

## PhD/Master Session 2019

Chair:
Martina POLIG, Science and Technology in Archaeology Research Center (STARC), Cyprus

A crucial aspect of the conference „Cultural Heritage and New Technologies“ was that it brought together researchers from different fields and backgrounds, creating a platform that enables and promotes the exchange of ideas. This discussion could only benefit from the input and perspectives of the young scientific generation. Their participation enriched the scientific ambient with their fresh views as well as gave them the opportunity to confront themselves with their peers in the context of an international conference. Therefore, we invited students and recent graduates to present their ongoing or finished Master or PhD thesis at the conference. New ideas, new ways of thinking, clever solutions, workarounds and critical thoughts were especially welcomed.

The topic of the presentation was within the scope of cultural heritage and new technologies. However, presentations that were within this year’s main topic “Monumental Computations – Digital archaeology of large urban and underground infrastructures” were given preference. The session wanted to encourage young scientists to present for their first time at an international conference. Only presenters, who had not yet given a presentation at this conference were accepted for this session. To facilitate and encourage the participation the conference organizers agreed that every presenter will get free admission to the conference.

# Infrared spectroscopy as a tool to estimate the age of wood

## How we can use the molecular decay of wood for dating purposes

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Bernhard SPANGL, BOKU University, Institute of Statistics, Vienna, Austria
Ena SMIDT, BOKU University, Institute of Physics and Material Sciences, Vienna, Austria
Michael GRABNER, BOKU University, Institute of Wood Science and Technology, Vienna, Austria

***Keywords:*** *molecular decay—wood dating—FTIR spectroscopy—Random forest model—dendrochronology*

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## Motivation and Background

The dating of wooden objects is of high relevance, as wood is preserved comparably well under various preservation conditions. Among these, waterlogged wood is especially often found in large quantities. Dry storage results either in situations of constructions sites as well as the Arctic region and desert zones. Another advantageous condition preserving wood is found in salt mines or other toxic environments (Rowell and Barbour, 1990).

Currently, wood is dated by means of either dendrochronology or radiocarbon dating. However, both methods have weaknesses and drawbacks, as samples might not be dateable or the costs might be rather high. The purpose of this master thesis was to use the molecular decay measured by means of infrared spectroscopy to establish a prediction tool for the age of a sample.

Fourier Transform Infrared (FTIR) spectroscopy is a common tool to evaluate the chemical composition of materials, especially organic matter. The method measures the vibrational signals of molecules or molecular groups induced by infrared light. It has been successfully applied in studies on the aging of wood, paper and charcoal (Trafela et al., 2007; Smidt et al., 2017). For statistical modelling of the spectra, an approach coming from the field of machine learning was applied—random forest models.

The aim of our work was to establish dating tools for wood based on the molecular decay measured by means of FTIR spectroscopy.

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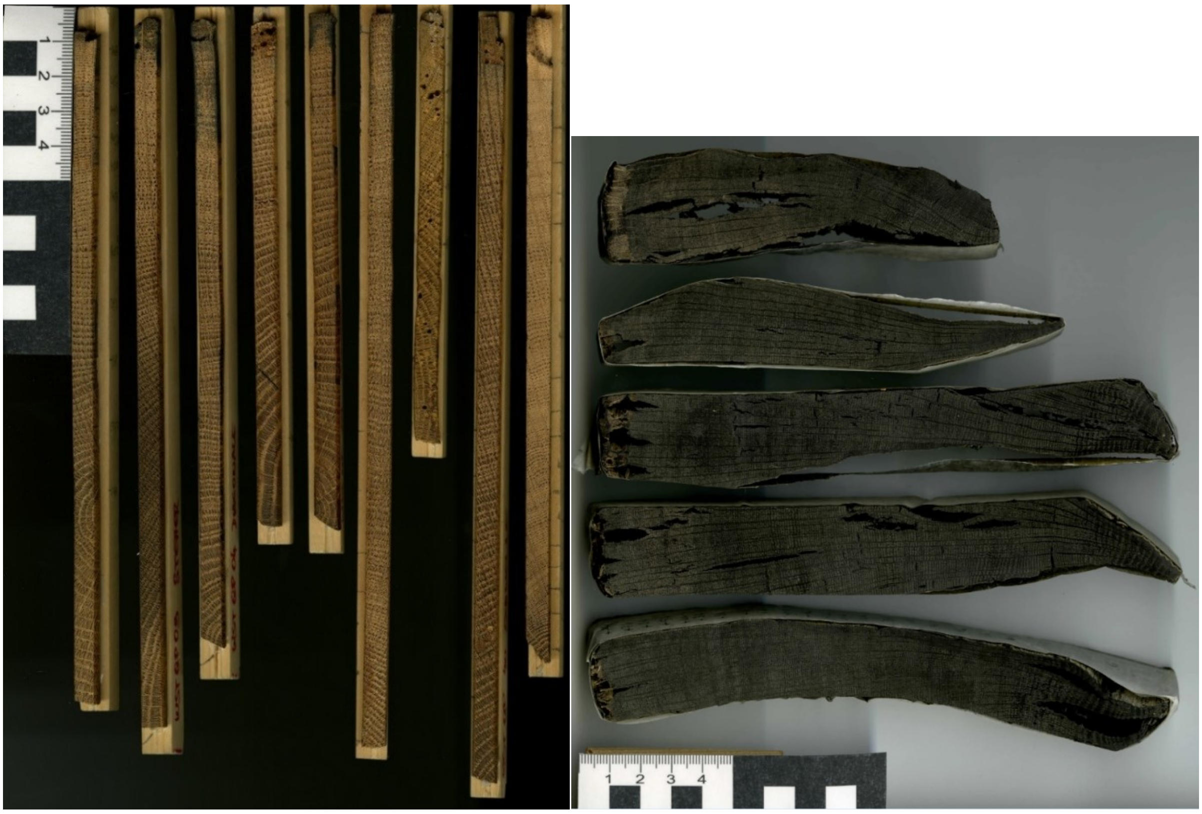
## Materials, preservation conditions, and methods

The sample set was comprised of wooden samples of different origins. Construction wood came from buildings in the cities of Hallein and Salzburg, St. Stephans Cathedral in Vienna and Heidenreichstein castle in Lower Austria. Waterlogged wood originated from a cold lake in the mountains of Dachstein massif in Upper Austria and the Roman Harbour in Weyregg, Upper Austria (Fig. 1). Salty environment was covered by samples from the prehistoric salt mine in Hallstatt, Upper Austria. Additionally, living trees were sampled to prove the aging effects were already measurable at the earliest stages. The storage conditions of construction wood can be described as dry and relatively moderate temperatures (usually protected against outdoor weather). Waterlogged samples were stored at mean water temperatures of 11 °C and below. Wood from a salt environment can be described as densely packed in a mixture of salt and clay (Tintner et al., 2018).



*a* *b*

*Fig. 1. a) Wooden cores from St. Stephans Cathedral, Vienna. b) cuts from the Roman harbor at Weyregg, Upper Austria (© F. Reiter).*

Wood of four different species/ genera was tested: spruce (*Picea abies*), larch (*Larix decidua*), oak (*Quercus* spp.), and fir (*Abies alba*), totalling 190 wooden pieces with 3533 performed measurements. Dendrochronology served as a reference method delivering the age for the calibration set. The ages of the samples covered around 3000 years for spruce, 2000 years for oak, 3500 years for larch, and 700 years for fir. Infrared spectroscopy was carried out in the mid infrared range in ATR (Attenuated Total Reflectance) mode. The polished solid surface of the wood samples was measured. A single measurement was (as far as possible) performed on a single tree ring. Thereby, the FTIR spectra could be assigned to a distinct year reference. Several regions in the spectra were selected to be included into further analyses. These areas can be assigned to different molecular groups originating from different chemical compounds of the wood. Dating tool were performed for each species/ genus separately.

## Results and Discussion

The band regions most relevant for the prediction varied among the species. For spruce and fir a region around 1730 $cm^{-1}$ was the most significant one. Fig. 2 displays the systematic decrease of this band region at exemplarily chosen spectra of different age. The band region can be assigned to acetyl groups in hemicelluloses (Schwanninger et al., 2004). This group had previously already been identified to be highly relevant in the wood aging processes of archaeological wood (Tintner et al., 2016). The molecular decay of oak wood was visible in, the acetyl groups, as well as characteristic bands of molecular groups in cellulose. For the larch model, a further region assigned to a resin band had to be included. The environmental aging conditions in living trees, waterlogged wood and construction wood led to comparable aging processes. Therefore, these conditions were combined in one prediction model. Salt environment led to slightly, but clearly different aging conditions and thereby diverging readings. Separate models for salt environment are necessary and already in preparation.

The prediction error for a single measurement varied from 367 years in the larch model, 274 years in the spruce model, 113 years in oak, to 97 years in the fir model. As FTIR spectroscopy can be performed easily on a high number of measurement points on a wooden artefact, the prediction quality of an artefact will increase depending on the number of measurements. It can be assumed that a prediction quality for artefacts between 50 to 100 years can be achieved for all species.

Drawbacks of the method are brittle parts of wood, where microbial decay led to stronger degradation processes. Also, the outer surface of construction wood facing compartment air displays an accelerated degradation rate of the significant band region around 1730 $cm^{-1}$. Furthermore, it has to be stressed that the models are restricted to selected environmental conditions (wood stored in a salt environment cannot be predicted properly).

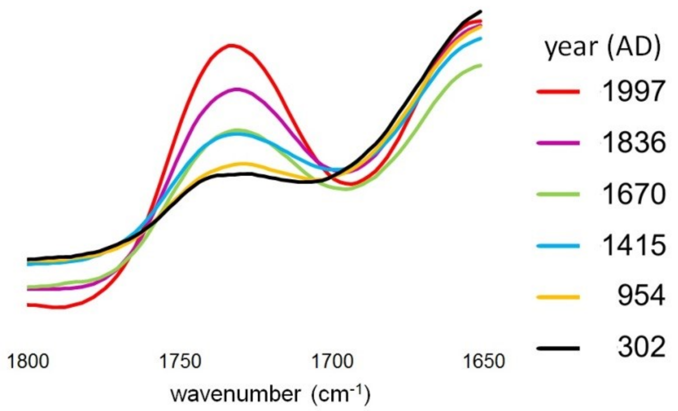



*Fig. 2. Molecular decay of acetyl groups in hemicelluloses of resulting in a band decrease around 1730 cm-1 in FTIR spectra. The year (AD) has been determined by means of dendrochronology. Measurements are randomly selected from spruce samples with different age.*

## Conclusion and Outlook

Within the master thesis, the potential of FTIR spectroscopy to detect the molecular decay of wood and its use for dating purposes was demonstrated. The established models are adapted for four common European tree species /genera (spruce, larch, oak, fir) covering between 3500 and 700 years. Prediction quality for a single measurement ranges from 367 to 97 years. As the quantity of measurements does not affect the costs of testing as much as in other procedures, artefacts can be predicted more precisely for the same price. Further models for different species and different storage conditions will be established in the near future.

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# Session:
# In Honour of Willem Beex!

Benno RIDDERHOF | Giorgio VERDIANI | Wolfgang BÖRNER

## In Honour of Willem Beex!

Chairs:
Benno RIDDERHOF, University of Amsterdam, The Netherlands
Giorgio VERDIANI, University of Florence, Italy
Wolfgang BÖRNER, Urban Archaeology of Vienna, Austria

*Willem Beex (1962–2019)* was a member of a special generation of archaeologists. Educated traditionally in the 1970's and 1980's Willem attended universities in Groningen and Amsterdam. In those days, Dutch students first had to get a degree in Art History before they were allowed to study archaeology. So Willem got his master in Art History with a specialization in early modern architecture in Groningen. Then he moved to the University of Amsterdam and studied Prehistory and his master thesis analysed Bronze Age burial mounds in Northern Europe.

The 1980s and early 1990s were a time of change and great opportunity in Dutch Archaeology. New digital techniques along with new theories and models were introduced in Archaeology. Databases and Theodolites and first-generation Total Stations and digital drawing changed the landscape of archaeology not only in the classrooms of the universities but also in research and fieldwork. And Willem was one of the first pioneers in the Netherlands.

This starting position enabled Willem Beex not to become a one subject or period archaeologist. With his theoretical, practical and field background Willem could and did work on all periods of archaeology and in many countries.

To give a few examples:

Willem worked as university teacher in Leiden and Amsterdam. He worked as a site supervisor in Italy, UK, USA and the Netherlands. He was a theodolite and total station specialist in Lebanon, Egypt and the Netherlands. He also was a regular visitor to conferences and one of the most active members in the Scientific Committee of the annual CHNT conference in Vienna.

This session honoured Willem's long and diverse career.

# Maastricht, the city, the maquette and the collection at the Palais de Beaux-Arts in Lille (France)

## Photogrammetry and digital twin creation for an ancient urban physical model

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Gilbert SOETERS, Municipality of Maastricht, The Netherlands

**Abstract:** During the CHNT 2017, while attending together one of the social events, Gilbert discussed with Willem Beex the possibility of scanning the famous maquette of Maastricht from 1750. Willem suggested a collaboration between his agency and the Dipartimento di Architettura (Architectural Department) in Florence, Italy, to start what clearly was a nice, involving, not easy and fascinating research and work, centred on a large maquette (about 6 × 7 metres) representing the old town of Maastricht in 1750. The Maquette was under restoration in Lille, France, at the Palais des Beaux-Arts, during the reorganization of the specific maquette room in that museum. A very good condition for a survey intervention. In the middle of 2018, the project was going to be supported financially by the Maastricht Municipality and soon there would be the need for an operative proposal and an effective presence in place to bring on the survey and the following post-processing. Willem announced the possibility to start the surveys in June 2018, it was the start of an interesting adventure with a very specific cultural heritage subject. The large size, the high level of details and the high expectations about the quality of the results needed a proper set of smart and technical solutions. The creation of a digital twin of the "Ancient Maastricht Maquette" was undoubtedly the first step to bring this heritage into the new information technology age, but also an excellent occasion to bring back the precious data from the past to match with the contemporary city, rising the value of the main building but also the precious witness of the old urban pattern and the past relationship with the territory. This paper will tell the story, methods, procedures of this last work with Willem Beex, completed without him, and here presented in his memory.

***Keywords:*** *Architecture—Cultural Heritage—Digital Survey—Structure from Motion—Image Matching.*

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doi: 10.11588/propylaeum.747.

## Introduction

Cultural Heritage is art, objects, part of human works connected to history and events. It is a puzzle of ideas and ideals. In it, complex issues, aims and wills brought to apply intelligent thinking to amazing solutions. Managing the territory, understanding the shape of the world is one of these cases. It comes with the efforts of the mind to reach the proper understanding and developing the needed abstractions. With the aim of reading, presenting and planning the use of the territories.

The realization of a maquette representing a city with all its surrounding territory, like those collected at the Palais de-Beaux-Arts in Lille (Tapié, 2006), was, in its time, a systematic and accurate process to gain the control of areas and guarantee a specific and (at all the effects) strategic knowledge of the towns and their surrounding territories. To allow such a result, two main elements entered the scene: the work of artisans and the best skills and practices about the cartography and territorial representation of that time. These two elements were coordinated to create a detailed model, a clear representation of the state of knowledge about the territories and their assets. The result replied to the need of combining the information gathered in place from maps, drawing, explorers, spies and visitors.

Each maquette in itself was not intended as an artwork. Thus the attention to details was a fundamental factor to allow the recognization of the use and features of buildings and structures. The artisans built these models with simple materials and then painted them to reach a realistic aspect. This was not a matter of innovation, while it was a quite common solution for the old architecture models (Knoll, 2007). The final result and effect brought it to be an admirable application of clever solutions. What arrived in present times creates a valuable impression. These models even after losing their original uses remain a unique witness of the past.

### The "Plan Relief" room at the Palais des Beaux-Art in Lille

The so-called "plan-relief" collection at the Palais des Beaux-Arts in Lille, France (Fig. 1), is a precious archive of maquettes hosted in a specific hall of the major Lille museum. At the time of their making the purposes of these exemplary artisan works were military at the one hand and on the other side they were prestige objects of the French King. The high level of details, the accurate representation of each building, of all the walls and fortifications, with great attention to the countryside, with all the trees, terrains, rivers, waterways, channels, stones, roads and paths, was due with the aim of allowing a perfect comprehension of the areas. All the cities and towns represented in this rich archive were settled in a geographic area with very complex borderlines, were the traveller was continuously passing (as it still happens now a day) between the borderlines of Netherlands, Belgium and France. Such a neuralgic area was not far from possible military operations and possessing such a collection of models was equal to possessing a clear knowledge of all the strategic issues and possible troop movements around these territories. The physical tridimensional model was then intended as a tool for planning "virtual" intervention of soldiers, armies, cannons, it was a reproduction of the reality aimed not to plan urban or architecture transformation (Carones, 2017), but for operating military-strategic interventions. In the time of peace, in the age of the European Community, the collection became a patrimony to protect and exhibit because of its incredible artistic value, it took then place in the Museum of the Palais De-Beaux-Arts allowing to the visitors to admire the skills of many artisans who realized each piece. A special set of models capable to tell a rich story about countries, past aspect of the cities with their former relationship with the territory. In between the numerous maquette: Lille (itself), Namur, Calais, Oudenaarde, Maastricht. A total of 14 cities, (six from French, seven from Belgium, one from The Netherlands). Composed of wood, printed or painted paper or cardboard, silk, tissues, sand and wires, on the scale of one to 600 (Warmoes, 2006). The models depict their subjects as they were from the 17$^{th}$ to the 19$^{th}$ centuries. Such use was not a special behaviour of the army divisions in this complex part of Europe (Pollak, 2010), creating models for military planning is well documented in other collections arrived in our days (Warmoes, 2012), the use of large and well-detailed maquette was a common tradition from that period, a state of the art technical solution aimed to give proper tools to the military planning. In the present time, the collection is not only a rich group of artefacts, a special set of artworks rich of details, but it is also always the witness of a former condition of the urban landscape (Constant, 2008). The collection allows admiring the significant transformations of these towns: all the maquettes present a clear separation between the urban area and the countryside, the limit of the urban centres are sharp, well defined. The town is contained inside its walls, and its limits quickly fade across a series of fortifications between the main walls and the land. The territory all around is mainly dedicated to agricultural activities, then it is represented in fields free from trees and bushes. All the networks of roads, streets and paths are accurately represented and modelled, to make possible the planning of routes for soldiers, horsemen or carriages.

### The ancient Maastricht maquette

In the specific, the Maquette representing Maastricht is made of 13 pieces, some of them representing the countryside out of the city area, some others with a detailed description of the fortifications and facilities all around the town and then a group of two large parts representing the town centre with all the walls, the main monumental buildings and all the urban tissue (see table 1 for details about each part). The structure of each part is based on a series of robust wooden beams. They cross beneath the surface of the "terrain" and exit from the inner upper borders to allow connection and blocking to the other pieces. The external border is characterized by a flat blue border. It is underlined with an upper and lower framework giving a "limit" and a graphical conclusion to the whole asset. The materials are not reflective, the paper and most of the details are well preserved or restored and there are few missing parts (small frames from the windows, some arches, some trees) or spots (like what is said to be a large wine spot on some buildings in the nearby of the Cathedral). All the pieces have a high level of details. The parts dedicated to the town centre as well as those representing the countryside show particulars, minor roads, divisions in the agricultural lots, minimal details from houses and fortifications. The River is well represented in all its morphology, complete of minor deviations and islands. This accurate description of the riverside is done with the same accuracy both in the urban and in the countryside areas. There are very few written indications directly on the model, like the name of the river and the arrow indicating the sense of flowing and, just in the sector number 9, two labels with a brass frame and covered with glass. One is larger and brings the indication "MAASTRICHT, Sur la rive gauche de la Meuse (Pays-Bas) 1752, échelle du 600 Rép 1803". The other, smaller and circular one, presents a compass indicating the North.

### The survey, techniques and operations

The first tasks in this part of the research were all pointed to the creation of a digital twin of the Maastricht maquette. The maquette, unmounted in its 13 pieces, was a quite complex subject, in need of different approaches accordingly to the various sizes and level of details. In the group of parts those representing the old town centre, with a very dense urban tissue, were two. All the other 11 were dedicated to the external fortifications of the city and the surrounding countryside. The ongoing restoration at the time of the survey was making things easy, while all the parts were separated and easily accessible. Defining the best digitalization solution took an accurate reflection: the choice between tools, their practical issues, results and following post-processing needs, was quite strategic before moving to Lille for some early test. The past case studies about the digitalization of a maquette are quite significant (Guidi et al., 2006), like the one about the large "Gismondi's Ancient Rome Maquette", an almost experimental work coordinated by Bernard Frischer and started from a 3D Laser Scanner survey (Guidi et al., 2008), or the survey of the maquette of the Gavi's Arch (Guerra and Vernier, 2011) operated on a wooden model using a pattern projection system. The accuracy of the survey tool was a fundamental aspect, thus, the extreme density of the urban pattern of some parts of the Maastricht Maquette, as well as the intention in having a well detailed and fully textured result, were two points pushing away from the hypothesis about using active survey systems based on lasergrammetry or pattern projection. Willem Beex was looking for the best possible result (Fig. 3), but it was clear that time was influencing the costs, and transportability of the tools for the survey was not a secondary factor. It was then decided to proceed by S.f.M./I.M. Photogrammetry (Guidi and Gonizzi, 2014) using a high-resolution medium format camera, a Fujifilm GFX-50s equipped with a Fujinon 32–64 mm zoom lens, so to have one of the best top choices about image quality at the time. The medium size sensor (33 × 44 mm), the high resolution (50 Megapixels), the quality of the lens and the extremely versatile and professional configuration of the controls were ideal for obtaining the best possible result. One of the possible issues was the minimum focus distance. The Fujinon 32–64 mm zoom lens has a minimal operative distance of 55 centimetres, perfect for close-up photography (Luhmann, 2011) but not strictly a "macro/micro" lens (Erlewine, 2011). At the same time, the angle of field (81° on the diagonal at 32 mm focal length, similar to a 25 mm on a full-frame sensor camera) was giving good options about coverage and creation of images with a proper perspective helping the reconstruction process (Linder, 2016). The light conditions were quite a doubt until the first test, so it was decided to use two remote flash units controlled by a remote trigger on the camera. The flashes were asked to be quite compact and powerful. With such requirements the Godox Witstro Pocket Flash AD200 was a good choice, it has a "Guide Number" (GN, the value expressing the strength of the light emitted by the flash unit) of 60 at 100 ISO sensitivity using the "bulb" naked head. This particular headlamp, projecting light in all the direction allows to have soft shadows ideal for photogrammetry, to make even more "shadowless" this light a specific dome diffuser by Godox was mounted on the flash unit, so to allow a very soft artificial light all over the scene. Two Godox Wistro Pocket Flash AS200 comes out as a well-working choice. The need for artificial light was double: creating proper exposure conditions in case of low light and filling the shadows from the available lighting. A first shooting test was made in July 2018 (Fig. 2), it was operated on two significant pieces, one mostly characterised by a dense urban pattern and the other with the countryside, hills, walls and fortification interventions. In this first test, all the picture were taken moving around each piece, using a very stable tripod and remote control (the Fujifilm App from a smartphone) to trigger the camera. Then, after seeing the final quality of the results and getting well satisfied with it, the second campaign was planned in September 2018. In this second phase, the final strategy was well refined, obtaining the authorization from the Museum about "hanging" the camera over the maquettes. In this way a specific tripod was organized, using two robust stands with a long horizontal bar. The camera was fixed on the bar using a photographic clamp, then the camera plus clamp unit were secured with additional steel cables and safety hooks to the bar (Fig. 4). This system allowed to move the camera parallel to each main sector of the maquette, taking pictures firmly, quickly and with the desired overlap, which was from a ¼ to ⅓ accordingly to the complexity of the sector.

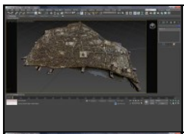
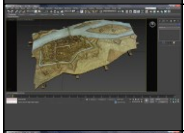
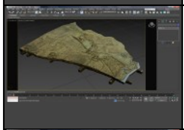
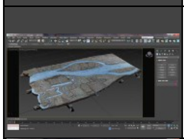
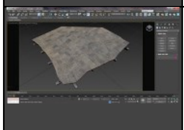
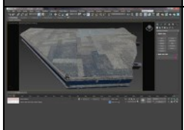
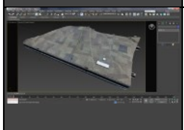
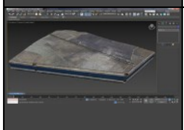
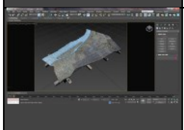
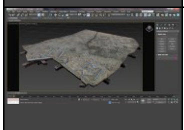
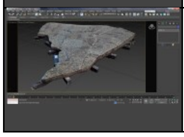
| Sector | Number | Description | number of top shots | number of side shots | date |
|---|---|---|---|---|---|
|  | 1 | Central part of the city | 325 L1 +75 L2 | 553 | 09/2018 |
|  | 2 | Walls, river and walled town expansion | 0 | 357 | 07/2018 |
|  | 3 | Countryside and fortifica-tions | 270 | 81 | 09/2018 |
|  | 4 | Countryside and external fortress | 242 | 91 | 07/2018 |
|  | 5 | Countryside and fortifica-tions | 267 | 116 | 09/2018 |
|  | 6 | River, countryside and fortifications | 167 | 143 | 09/2018 |
|  | 7 | Countryside | 0 | 302 | 09/2018 |
|  | 8 | Countryside | 0 | 134 | 09/2018 + 01/2019 |
|  | 9 | Countryside (part with label and com-pass) | 81 | 177 | 09/2018 |
|  | 10 | Countryside | 0 | 192 | 09/2018 + 01/2019 |
|  | 11 | River, countryside and fortifications | 147 | 224 | 09/2018 |
|  | 12 | Countryside | 245 | 118 | 09/2018 |
|  | 13 | Countryside | 0 | 160 | 09/2018 |

*Table 1. The parts of the maquette and the data about their photogrammetry (© G.Verdiani, G. Soeters).*

For the central portion, the part numbered as “1”, representing the main settlement of the city, the shooting from the bar was done at two different heights, keeping the same focal length and similar overlapping. This was done with the purpose to have two different results at different resolutions, with the one taken from higher aimed to produce a more “light” version of this very detailed central part. For all the other sessions it was used a single height. This solution was adopted only for the sectors with a high level of complexity, with many variations in the vertical articulation, buildings and complex terrain modelling.

For the sectors representing quite flat parts it was preferred a simple “turning around series of shots, so to accelerate the overall duration of the operations. To complete the coverage of all the details and streets, a specific sequence of shots taken moving in a circle around the sector was planned for all the parts. The data about the full photographic campaign (final shots effectively used) of each sector are enumerated in Table 1.

When all the pictures were processed and the 3D model done, a final session of shooting, to integrate the existing datasets was accomplished in the middle of January 2019. But at the end of January 2019, Willem Beex left us. The sad event happened suddenly and immediately after the completion of the third, integrative photogrammetry campaign. The work in Lille was completed, it was time to bring to end the photogrammetric processing. The work was brought on and to its end without him, still feeling his strong guide to bring on seriously and tirelessly the project with a proper level of quality.

**Data treatment**

The processing of the sectors composing the large maquette started immediately after the very first test campaign. It was important to find solutions capable to keep a proper level of details and at the same time create still manageable 3D digital models. The data treatment remained the same since the beginning, while the results were immediately so good that there was no need to take again pictures for the parts used during the test.

The first step was the Image selection, removing all the pictures afflicted by a case of shaking blur, non-accurate focusing, or simply the redundant ones (almost the same point of view). Thus the number of pictures to be removed was very minimal, about 10 to 20 for each sector. Most of them were simply the same shot taken without firing the flashes: in facts, during the second campaign, it happened to have some overheating issue from the flashes, solved with a reduction of the operative speed, taking pictures at a slower pace, waiting a little longer time between each shot. This procedure turned out as the best solution to avoid this kind of stops. The smooth, uniform light, practically shadowless for all the shots, turned out to be so homogeneous to allow direct use of the JPEG images. The extremely high quality of the sensor was well completed by the minimal destructive compression applied to the final images by the Fujifilm camera: the resulting JPEG images ranged from 34 Mb (pictures with urban tissue/textured terrain on all the frame) to 22 Mb (pictures framing a large portion of the floor around the maquette).

The whole processing was then brought on using the Software Reality Capture, using a classic production workflow starting with the alignment of the pictures; followed by the polygonal mesh creation (Fig. 5). At this point, after a first archiving of the photogrammetry project, a new copy of the model received the process of decimation to reduce the number of triangles composing the mesh. For each sector, the decimation was set with a polygonal model mesh target value of 15 million of triangles. The simplified result was then edited to solve some minimal defects, like isolated triangles and holes. All was done using the internal functions in Reality Capture[1]. The simplified model was then the base for creating the texture. This was generated using the resolution at the value of 16K, equal to 256 Megapixels (Fig. 6). The last step of the process was the exporting of the final model in OBJ/MTL+JPG (mesh plus texture with an MTL file containing the parameters for the texture) formats.

The OBJ model was then imported into Autodesk 3D Studio Max[2] (Fig. 7). The following step in this program was to put in scale all the sectors using measures gathered directly on the objects, annotated and kept for this passage. Each part was prepared in a single MAX file and put in a specific folder with all the images needed for texturing. For each part there was the preparation of a dedicated animation rendering, exploring with a perspective view the single part in its main features and characteristics. The setting of each animation got a duration from 45 seconds to one minute and a half according to the complexity and articulation of the part. This was done to create a first (difficult to repeat) visit to the unmounted parts of the maquette.

The completion of this phase took some times and the first version of the digital twin of the Maquette from Lille was presented in Maastricht on the 14th March 2019, a date defined time before with Willem, just in coincidence with the re-opening of the “Plan-Relief” room at the Palais-des-Beaux-Arts which took place on the 16th March. This was a key event for the completion of the model preparation tasks as well, while at that time the whole model was put back in its unity and with new lighting setup. So, it was extremely interesting to take a look and check the final result, take some pictures of the new setup and define the final calibration of the colours of the textures accordingly to the exhibition appearance.

The completion of this phase took some times and the first version of the digital twin of the Maquette from Lille was presented in Maastricht on the 14th March 2019, a date defined time before with Willem Beex. Just in coincidence with the re-opening of the “Plan-Relief” room at the Palais-des-Beaux-Arts, which took place on the 16th March. This was a key event for the completion of the model preparation tasks as well, while at that time the whole real model was put back in its unity and with new lighting setup. Seeing the new room with all the parts brought back to a single maquette was extremely interesting. Not only for the curiosity but to give some last retouch to the colour scale of the digital model and reduce the differences between the virtual and real maquette. This was done taking some pictures of the new setup and defining on them the final calibration of the colours of the textures accordingly to the exhibition appearance.

### Optimization of the alignment between parts

After the reopening of the “Plan Reliefs Room” in Lille, the work on the digital model was ready to be completed. The first task was to optimize and bring to a final version the alignment between the digital parts. This was obtained in Autodesk 3D Studio Max, checking, moving, rotating, aligning and

1 RealityCapture: Mapping and 3D Modeling Photogrammetry Software - CapturingReality.com

2 3ds Max | 3D Modeling, Animation & Rendering Software

using the specific Maxscript "3-Point-Align 1.2" by M. Breidt[3]. No deformation tools were used on the starting models, this was a possible option, but it was preferred to avoid this kind of solution (Fig. 8). This alignment was not easy for two main reasons: for first every single part was not necessarily placed in the same horizontal plane than it will reach when combined with all the others. Secondly, the beams and connections were probably subject to some bending and movements when connected all together. The digital version is a "rigid" representation of elements with a certain level of elasticity. Thus, after a generous series of tentatives, a realistic and efficient alignment came out.

### Recalibration of the global colour palette

Once the alignment between parts was completed, it was time to finish the processing with a final colour calibration of all the textures. In facts, the slightly different lighting conditions at the moment of the photogrammetric survey produced a certain number of unbalanced colour dominances between parts (Fig. 8). The correction was done in two steps: a first global colour balancing between textures and a second passage on the single textures balancing the colours about the colour scale appearing in the final setup at the Palais des Beaux-Arts in Lille. All the colour balancing work was done using Adobe Photoshop[4]. To have a very fast and practical intervention on these textures, it was preferred operating directly on the images produced during the export of the model, the maps where easily corrected and balanced, checking little by little the progress with a series of rendering from Autodesk 3D Studio Max.

### Future perspectives

Some testing for 3D printing from the final digital model was a part of the final data treatment at the Dipartimento di Architettura in Florence, the resulting model simply based on white monochromatic resin, was produced using a Formlabs[5] Form2, a 3D Printer using SLS Technology (Selective Laser Sintering), the needed material was an amount of 90 ml for every single part of the model and a printing time of about 10 hours for each part. Both the tests were done on the digital model of the piece number one, the one dedicated to the old town centre. Beyond these very early tests, the digital twin of the maquette is a versatile and accurate model, open and available to the Maascrticht Municipality for digital application and create ideas. After obtaining the data from Firenze, the Municipality of Maastricht organised an inspirational session with several stakeholders to decide what to do with this data in the storytelling of the history of Maastricht. One of the participants, Rob van Haarlem, saw multiple possibilities and his firm Tijdlab, together with the firm Dutch Rose Media, arranged a substantial grant to start a new project. in this project there are a few goals: to render the data to a more realistic level, to use volumetric video to tell the stories in a very vivid way and to give a realistic image of life in the city of Maastricht in 1750. 30 students of the Breda University of Applied Science came up with several ideas of stories to tell. These ideas will be further analysed in the next months and decided which stories to tell and how to perform them. The digital model has brought the possibility to share and use the large ancient maquette to new and creative conditions, making

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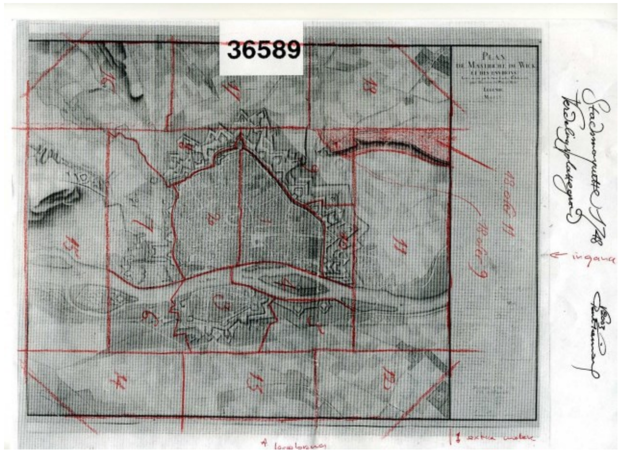
[3] Freeware, available at http://www.scriptspot.com/3ds-max/scripts/3-point-align (Accessed: April 2020).
[4] Adobe Photoshop webpage: https://www.adobe.com/products/photoshop.html (Accessed: April 2020).
[5] https://www.3dsystems.com/ (Accessed: April 2020).

possible to “bring” this part of the history of the town back to its original place after 270 years since its realization.

## Figures

*Fig. 1. Lille (France), Palais De Beux-Arts, Plan Relief Room, today (© G.Verdiani).*




*a* *b*

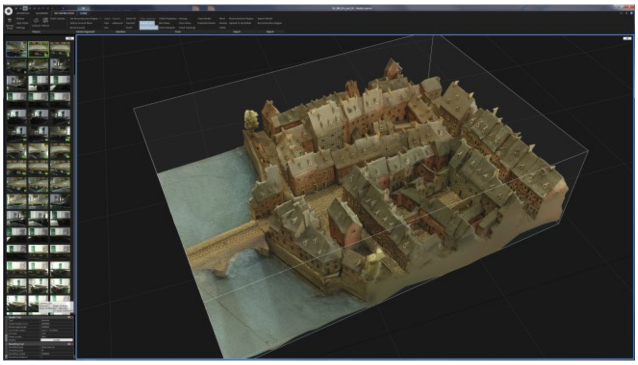
*Fig. 2. Starting the photogrammetry in Lille: a) one of the sectors used in the first test (© G.Verdiani, G. Soeters). b) old map with the original subdivision of the sectors (© Archive of the Palais des Beux-Arts in Lille)*

*Fig. 3. Planning and operating in Vienna and Lille with Willem Beex (© G. Soeters, CHNT Wien).*

*Fig. 4. Photogrammetry operations at the Palais des Beux-Arts in Lille (© G. Verdiani).*

*a* *b* *c*

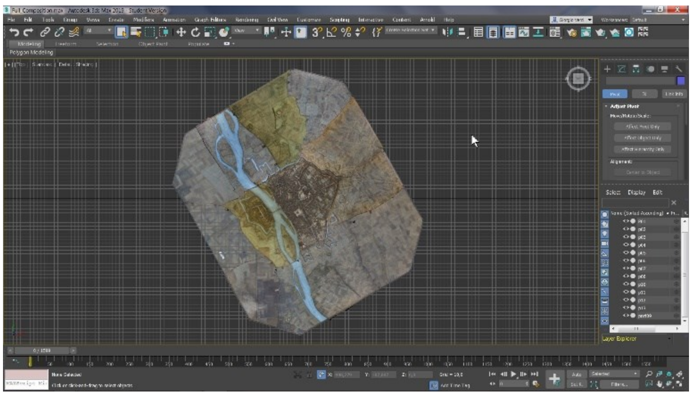
*Fig. 5. a) b) c) First results from the Photogrammetry of the sector number one, representing the main town centre (© G. Verdiani).*




a b

*Fig. 6. Photogrammetry processing: a) a portion from the urban fabric b) a sector completely modelled and textured (© G. Verdiani).*

*Fig. 7. Photogrammetry processing: final result from the central sector (part 1) (© G. Verdiani).*




a b

*Fig. 8. Reunion of all the parts: a) before the colours balancing. b) after the colours balancing (© G. Verdiani).*

*Fig. 9. Detail from the final digital model (© G. Verdiani).*

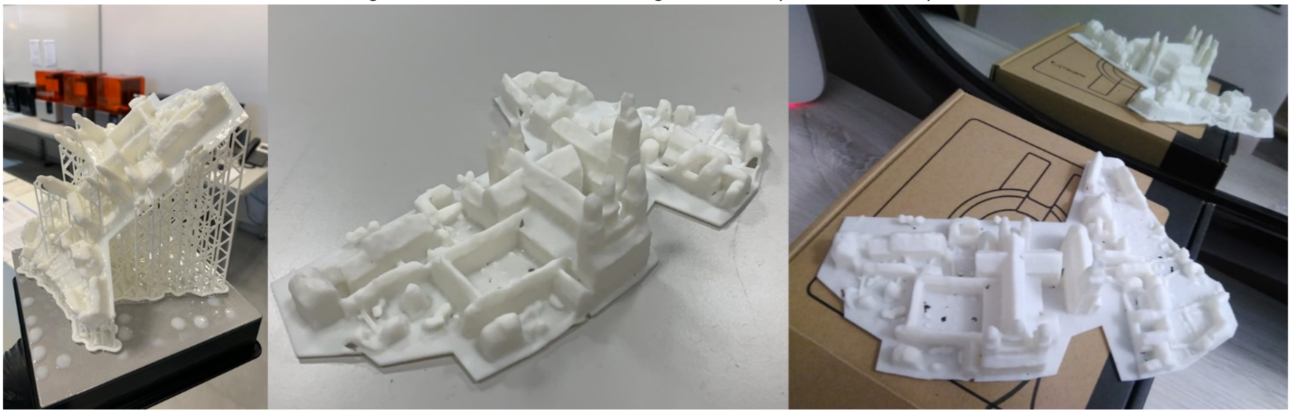


*Fig. 10. 3D Print tests from the digital model (© G. Verdiani, LMD DIDALABS, DIDA Florence).*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A descriptive video about all the photogrammetry of the Maastricht maquette is available at https://www.youtube.com/watch?v=hTKb8nZ0WJk&t=49s

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# Session:
# Lighting in Archaeology and Cultural Heritage

Rebeka VITAL | Costas PAPADOPOULOS | Dorina MOULLOU |
Lambros DOULOS | Pedro LUEGO

## Lighting in Archaeology and Cultural Heritage

Chairs:
Rebeka VITAL, Shenkar. Design. Engineering. Arts, Israel
Costas PAPADOPOULOS, Netherlands
Dorina MOULLOU, Greece
Lambros DOULOS, Greece
Pedro LUEGO, Spain

***Keywords:*** *heritage—archaeology—lighting, simulation—visualization*

Lighting, as a topic of theoretical, methodological, and practical endeavors crosses multiple fields and disciplines. Although it has been a neglected element in the interpretation of built environments, and consequently of humans' experience and perception, a renewed interest, especially in the last decade, has made light a key component in heritage discussions. This session focused on the cross-section between these two broad fields, namely heritage and lighting, in theoretical, methodological and technical applications, such museum designs, heritage sites' development and archaeological interpretations. The aim of this session was to discuss how illumination affects our perception and appreciation of heritage and plays a major role in our understanding of its past and current spatial, temporal, aesthetic and cultural aspects.

# Daylight scattering by late antique window glass from Ephesus

## Reconstructing the distribution of daylight in lost architecture

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Andreas NOBACK Technische Universität Darmstadt, Germany
Franziska LANG, Technische Universität Darmstadt, Germany
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**Abstract:** Starting from the 1st century CE, the availability of window glass throughout the Roman empire fosters the utilization of daylight in architecture. Due to features introduced by manufacturing, it affects the spatial distribution of daylight in buildings, and thereby the visual perception of architecture. Finds of window glass in the context of a mixed-use, residential house, located in a late-antique–medieval urban quarter in Ephesus, ask for a sound understanding of these immaterial aspects of architecture on the perception and utilization of buildings. The reconstruction of the building's illumination is challenging, since it has to replicate the effects of fenestration on admitted light, and therefore requires models of the light scattering by window glass. To prepare such a reconstruction attempt, two data-driven modelling techniques are evaluated. One is based on the direct characterization of light scattering by gonio-photometric measurements. The other technique employs ray-tracing on geometric surface models of the glass micro-structures, acquired by confocal microscopy, to derive effects on light scattering. The exemplary application of the techniques to an exemplary glass fragment from the site provides two models of the sample's scattering properties, including effects of corrosion and other alteration mechanisms. Both modelling techniques achieve qualitative accordance and demonstrate the applicability of the resulting models in daylight simulation. Quantitative differences between the two models indicate the importance to also account for effects by the glass volume and inclusions. The research lays the foundations for the planned modelling of glass based on replicated samples and processed finds, and shall ultimately lead to a plausible reconstruction of the building's illumination in late antiquity.

***Keywords:*** *Roman window glass—Ephesus—daylight simulation—material modelling—BSDF*

**CHNT Reference:** Grobe, Lars O.; Noback, Andreas; Lang, Franziska; Schintlmeister, Luise, and Schwaiger, Helmut. 2021. Daylight scattering by late antique window glass from Ephesus: Reconstructing the distribution of daylight in lost architecture. Börner, Wolfgang; Kral-Börner, Christina, and Rohland, Hendrik (eds.), Monumental Computations: Digital Archaeology of Large Urban and Underground Infrastructures. Proceedings of the 24th International Conference on Cultural Heritage and New Technologies, held in Vienna, Austria, November 2019. Heidelberg: Propylaeum.
doi: 10.11588/propylaeum.747.

## Introduction

### Glass and daylight in late antique building

Since the advent of window glass, first used in Roman baths of the 1st century CE (Baatz, 1991) and soon applied in other public and private buildings, the availability of daylight in architectural spaces is inseparably intertwined with the practice of glassmaking (Foy and Fontaine, 2008; Michielin, 2019). Finds from numerous locations indicate that in late antiquity, window glass was readily available throughout the empire. Primary production of Natron glass appears to have been centralized close to the sources of raw materials in the Near East, and nourished the trade with glass chunks, that were then processed to secondary products such as window panes in workshops that were spread over the entire empire (Degryse et al., 2014). Since the end of the 2nd century CE, window glass was mainly produced from blown glass cylinders, that were cut, unfolded, and flattened to panes with typical sizes of 200 mm to 800 mm (Komp, 2009; Arletti et al., 2010). Despite the inclusion of bubbles in the glass volume, such panes are assumed to achieve a higher clarity than formed or crown glass due to their smooth surfaces (Grobe et al., 2019).

The chemical composition of glass, as well as the surface irregularities and inclusions that result from its artisanal processing (Komp, 2009) shape the spectral and spatial distribution of transmitted light, and thereby the visual perception of the illuminated interior (Noback et al., 2018). While the spectral composition of transmitted light mainly affects colour perception, scattering by the glass modulates the distribution of light in the attached architectural space and on its surfaces, and affects the appearance of the window panes that can allow a view to the outside in the case of clear glass, or lighten up and act as large area sources under direct sunlight in the case of diffuse scattering (Noback et al., 2017; Noback, 2019; Grobe et al., 2019). The resulting luminous environment is not static, but continuously changing with the external sky conditions and—in the case of direct sunlight—the solar geometry (Inanici, 2014).

### Reconstruction and daylight simulation in historical science

The analysis and reconstruction of Roman and late antique interiors have a long tradition in building history (Demetrescu et al., 2016). Studies of daylighting in this context are however rare and often depend on assumptions in lack of empirical data (Papadopoulos and Earl, 2014). Computational simulation of light propagation in three-dimensional models is employed in building design and optimization (Ochoa, 2012; Jones, 2017), but can also be applied to evaluate the illumination of lost, reconstructed architecture (Grobe et al., 2010; Devlin, 2012; Earl et al., 2013; Papadopoulos and Earl, 2014; Happa et al., 2012).

Measurement and modelling of the optical properties of window glass are key elements of such simulations, if daylight is the primary source for illumination, and bridge a gap between material culture and sensory studies (Noback, 2019). Models of the effect on the spectral composition of transmitted light have been developed and applied in historical sciences (Cerise et al., 2012; Thanikachalam et al., 2016). Only few attempts to replicate scattering by surface irregularities and inclusions as characteristic for historic glass, as well as translucent tiles, have been made, that typically rely on simplified measurement and modelling techniques (Patay-Horváth, 2016). This is contrasted by the rapid development of characterization (Apian-Bennewitz, 2014) and modelling techniques

(Ward et al., 2014; Lee et al., 2018) in the field of building science, that support the development and application of optically complex fenestration addressing an increasing demand for comfort and energy efficiency (Kuhn, 2017). Advanced measures of the spatial distribution of daylight in buildings, the gonio-photometric characterization of scattering by fenestration, and its modelling in daylight simulation have just recently been demonstrated in few, targeted studies (Monteoliva et al., 2019; Grobe et al., 2019; Noback et al., 2017).

### Challenges in the modelling of Roman window glass

Transmission through modern, clear float-glass can be modelled either by Fresnel equations as a function of the incident direction ($\theta_i$), and the index of refraction and absorptance of the glass substrate, or by fitting polynomials to transmission measurements to account for the effects of coatings and multiple panes in modern fenestration (Karlsson, 2000). While any such perfectly clear glass has the property that the direction of light is not changed by transmission if both surfaces of the pane are coplanar, Roman window glass features surface irregularities and inclusions in the substrate that cause scattering, e.g. the deflection of transmitted light. Gonio-photometers acquire this spatial modulation of light, that is described by the “Bidirectional Scattering Distribution Function” (BSDF) (Heckbert, 1991; Stover, 2012) as the light transport through a specimen for any pair of incident and outgoing, scattered directions $(\theta_i, \phi_i, \theta_s, \phi_s)$. The BSDF is implicitly defined by the Rendering Equation (Kajiya, 1986) and relates incident ($L_i$) to scattered ($L_s$) radiance:

$$L_s(\theta_i, \phi_i, \theta_s, \phi_s) = \int_{\theta_i, \phi_i}^{\omega_i = 4\pi} BSDF(\theta_i, \phi_i, \theta_s, \phi_s) \times L_i(\theta_s, \phi_s) \times \cos\theta_i \, d\omega_i$$

Numerous models of the function exist that allow for fitting to measured BSDF data, or that can be parametrized based on few, established optical measurements or by known, physical meaningful properties such as e.g. surface roughness (Walter, 2007; Dai et al., 2009; De Rousiers et al., 2011). The lighting simulation software RADIANCE models translucency by applying the Ward reflection model (Geisler-Moroder and Dür, 2010) to transmission. This model has been employed in the modelling of Roman window glass, but is of limited generality since it represents directional transmission by a Gaussian peak based on a surface roughness parameter that is independent of the incident direction (Noback et al., 2018).

Data-driven modelling addresses this limitation and approximates arbitrary BSDFs by interpolation between discrete values (Ward et al., 2014). To achieve high directional resolution with compact representations, compression such as wavelet transforms (Wu et al., 2019), and reduction algorithms generating models of adaptive resolutions (Ward et al., 2012) are employed. The latter has been implemented in RADIANCE and is commonly referred to as the tensor tree model, due to the hierarchical data-structure that results from merging elements of an initial tensor that represent adjacent regions where the slope of the BSDF is low.

The properties of archaeological finds are not identical to those of window glass when it was in use. The characteristics of the sample rather form a convolution of its original properties, caused e.g. by glass composition and glass-making techniques, and later deterioration, caused e.g. by corrosion and contamination. Even a perfect model of the archaeological find therefore does not replicate the effects of window glass in its original condition on the illumination of a building. Reconstruction of the latter consequently requires both,

- a general and accurate model of irregular scattering, and

- the elimination of the effects of corrosion and other deterioration mechanisms in the simulation.

We hypothesise that the primary cause of light scattering on Roman window glass is the structure of its surface. Two approaches are currently being evaluated by the authors to isolate deterioration of the glass, and to reconstruct its original light scattering properties: The temporary "healing" of surface defects by sealing small-scale cavities, and the replication of Roman window-glass by means of experimental archaeology. Application of either method would then allow to reconstruct the light scattering properties of the sample in its original condition by data-driven BSDF models, that can be generated directly from gonio-photometric measurements, or deduced by ray-tracing on the acquired micro-geometry of the surfaces.

### Objectives

Aiming at a systematic research on the optical properties of Roman window glass of different origins, times and production methods as well as their impact on the development of fenestration, use and architectural typology, we describe the first outcomes of the development of modelling methods:

Testing our hypothesis, that light scattering is caused by the surfaces and hardly affected by the glass volume,

the development of data-driven transmission models by direct measurement of light scattering, and by the acquisition of the surface geometry and ray-tracing, and

the exemplary application of the resulting data-driven BSDF models in daylight in daylight simulation.

The elimination of deterioration effects, e.g. by the experimental replication of samples, or the proposed healing of surface defects, have not been covered yet.

## Late antique window glass in a mixed-use house in Ephesus

### Mixed-use houses in a late-antique–medieval urban quarter

A series of earthquakes in the 3rd century CE caused a sudden end to the heyday of Roman Imperial Ephesus. It took until the mid of the 4th century CE that reconstruction work has been undertaken (Ladstätter, 2019, p. 21). In the course of these measures, the lower city developed into the new religious and political centre of the late antique provincial capital: along with the construction of large public buildings, both profane and sacred in nature (Ladstätter, 2019, pp. 28–29), also the establishment of private residential quarters in the area of the former harbour gymnasium and the adjacent square—the so-called Halls of Verulanus—took place. A part of this residential area has been unearthed from 2011 until 2018 (Fig. a,b) and showed a series of three independent houses differing in size and decoration (Schwaiger et al., 2020). They are located right south of the bishop's church (Church of Mary) along a street which is accompanied by a portico. The buildings have been erected by the end of the 4th / beginning of the 5th century CE and have been in use until the second half of the 7th century CE, when they were destroyed by fire. The westernmost house and the one in the middle resemble imperial courtyard houses, whereas the easternmost house has a courtyard without

a b c

*Fig. 1. Three excavated houses (a, b), marble floor in the largest house in the west (c). (© Niki Gail, ÖAI / ÖAW).*

columns. Via entrances to the north, one could access the courtyards located in the inner of the house, which served as places of communication and dividers. Rooms grouped around these central spaces are differing in function and equipment. The rooms closer to the street in the north show clearly that they have been used for commercial and manufacturing purposes (Schwaiger et al., 2020). Especially the largest house in the west shows a series of representative rooms in the south (Fig. 1c, 1.16–1. 20 in Fig. 2). They show a lavishly decorated interior with mosaic and marble floors as well as the remains of wall paintings imitating marble revetments. In addition, the finds recovered from these rooms clearly identify them as spaces serving for representative needs of the house owner.

Since the house has not been abandoned but suffered severe destruction while being in use, all the inventory is preserved inside the rooms. In addition, elements of furnishing like the remains of doors, decorated beams and even window panes have been found. Hence, the whole furnishing and inventory remained within the destruction layers.

## The glass finds

Large amounts of window pane fragments were found in house 1, the largest of the three units with an area of 764.70 $m^2$, located in the west of the urban quarter. The majority of the fragments is in a very good state of preservation and was unearthed primarily along the walls of richer, more prestigious rooms of house 1 (Fig. 2). Several almost completely preserved window panes have dimensions of around 150 mm×210 mm. The fragments were made of yellow-brown or green coloured glass with a thickness varying from 1.5 mm to 5.0 mm.

Of the various known techniques for the production of Roman window glass (Haevernick, 1981a; 1981b; Von Saldern, 1980, p. 91; 2004, p. 201; Baatz, 1991; Kanyak, 2009), two could be attributed to the finds. Almost all the panes are cylinder-blown. These finds are shiny on both sides, show a slightly streaky surface and elongated air bubbles. Three fragments are of the “matt-glossy type” with characteristics of casting. They feature one rough surface and they are also very thick compared to cylinder-blown glass. One such fragment shows the trace of a tool (imprint of a pair of pliers), used to stretch the corner of the pane.

A total of 5273 fragments were classified into colour groups and weighed (total weight: 27.96 kg, Fig. 3). The yellow and brown coloured pieces make up 53 % of the total weight and 39 % of the total number of fragments. The green and aqua coloured fragments make up 41 % of the total weight and 49 % of the total number of fragments. Since glass breaks very easily, both very small (10 mm to 20 mm) and larger fragments (100 mm to 150 mm) are present. The state of preservation of the fragments varies greatly. Glass layers of 3 mm to 4 mm peel off the surface of pieces that are strongly affected by weathering. Thus, we cannot expect that the original state of the surface and the thickness of the fragment have been preserved.

It is still unclear how the window panes were installed. Frames could have been made of wood or marble as excavated in the Vedius Gymnasium (La Torre, 2008, p. 286) or the panes were placed in the moist mortar. Bronze frames with glass panes are known from the baths near the forum in Pompeii (Mau, 1899, p. 199).


*Fig. 2. Density of window glass finds overlaid on the plan of house 1 (© Katharina Sahm, Luise Schintlmeister).*

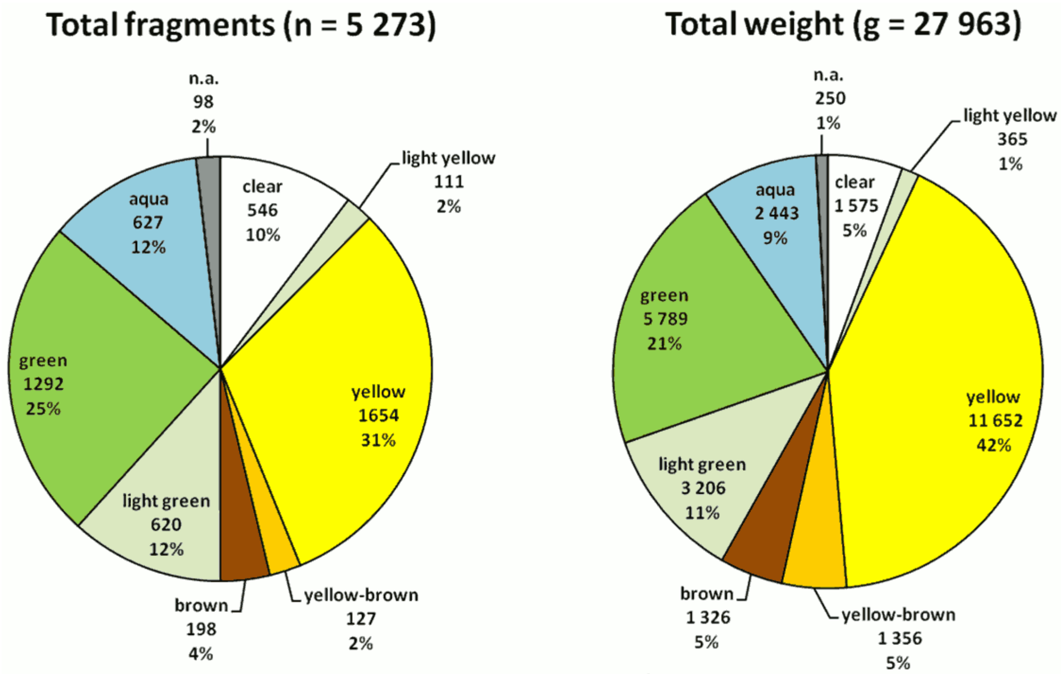



*Fig. 3. Frequency and fraction of glass finds of different colours in house 1.*

## Sample and data-driven modelling methods

Two data-driven models of the sample's light scattering properties are developed from the gonio-photometric measurement of the BSDF, and from the surface geometry acquired by confocal microscopy.

### An exemplary sample of late antique window glass

One sample was selected from the glass finds for a detailed characterisation, and to develop and test methods to model its light scattering properties as described in the subsequent sections. Consequently, this research does not provide a representative model for all the different fragments of window glass found in the site, but aims at testing methods for the characterization and modelling of late antique window glass.

The selected specimen is of approximate dimensions 70 mm×50 mm×3 mm (Fig. 10 a). Characteristic for the cylinder-blown type are its two flat and rather smooth surfaces, illustrated by the pronounced contrast that allows to read a text seen through the sample when it is placed directly on top of a printed sheet. Microscopic structures, that cover different regions of the surfaces at varying degree, cause diffuse scattering and are attributed to deterioration effects due to their non-uniform of the sample that appears to follow the curved longer edges and not the shorter, one of which is straight and may be a section of the original window-panes edge. A closer view reveals iridescence, a typical effect of laminar decomposition mechanisms that are caused e.g. by corrosion. The yellowish tint of the glass is assumed to be an original feature due to the chemical composition of the bulk material. The overall condition of the sample, compared to other exemplars of the collection, is considered good.

**Modelling light scattering based on gonio-photometric measurements**

Light scattering by the sample was directly measured by means of the BSDF. A scanning gonio-photometer was employed (Fig. 4), that acquires the distributions of scattered light by varying the directions of an illuminating light source and a detector relative to the sample by mechanical movement (Apian-Bennewitz, 2010). To ensure that the projected beam diameter on the sample does not exceed the specimen's width under oblique illumination by a stabilized 4 mW laser source with a peak wavelength at ≈ 520 nm, located between the maxima of human photopic (≈ 555 nm) and scotopic (≈ 505 nm) response, was employed in the measurement. The measurement is performed relative to a prior characterization of the illuminating beam rather than relying on a prior calibration.

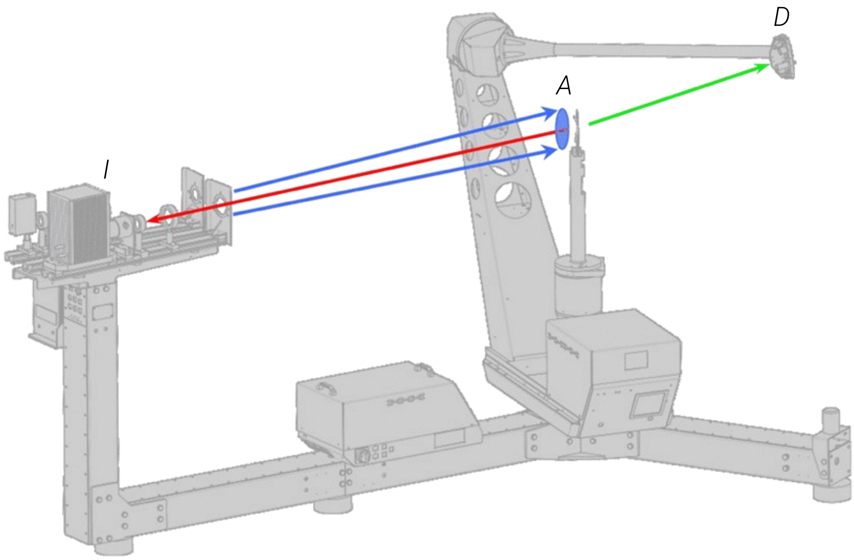



*Fig. 4. Scanning gonio-photometer. Light scattered from the sample region A (blue), illuminated by illuminator I from incident direction $\theta_i$, $\phi_i$ (red), is recorded by detector D at outgoing direction $\theta_s$, $\phi_s$ (green) during its continuous movement on a configurable scan path. Illustration (Grobe, 2018) based on image © Peter Apian-Bennewitz.*

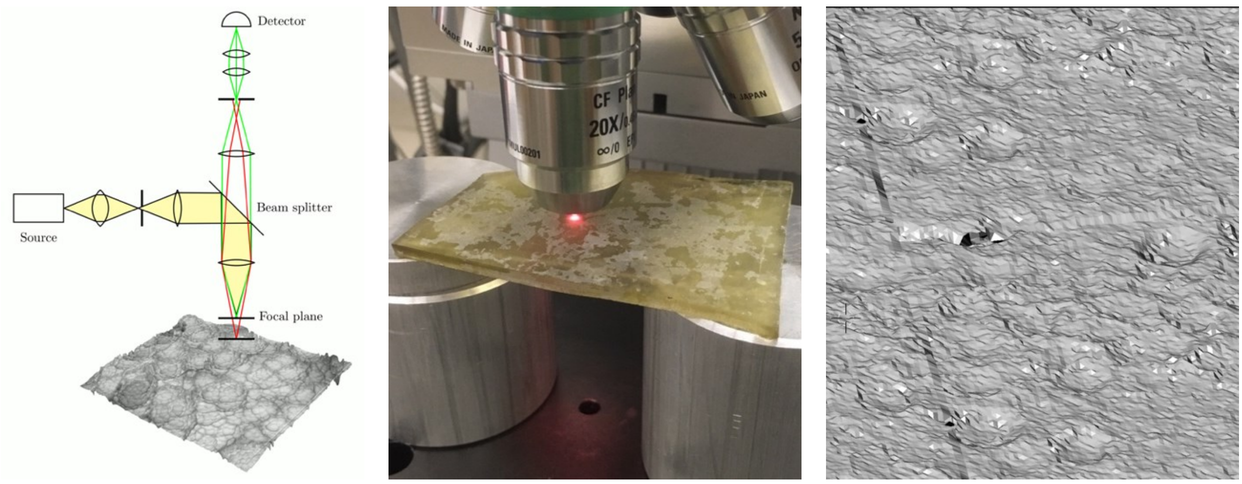



*Fig. 5. Design principle of a confocal microscope (a), sample during acquisition of its surface geometry (b), and resulting, triangulated surface relief (c, all surface properties were set to opaque for illustration).*

The sequential measurement of the BSDF allows to adapt its spatial resolution, allowing to e.g. refine peak regions, and covers a dynamic range that accounts for distinct specular peaks as well as the background of straylight by diffuse scattering. Assuming isotropic transmission, the hemispherical distribution of transmitted light was recorded in terms of illuminance at a dense set of > 150,000 arbitrary outgoing, or scattered, directions ($\theta_s, \phi_s$) for few incident directions defined by varying off-normal angle ($\theta_i$) but constant angle ($\phi_i$) in the sample plane. The coordinate system is relative to the sample.

The measured BSDF was exported as one tabular data-set per incident direction, with data-columns $\theta_s, \phi_s$ and the corresponding value of the "Differential Scattering Function" (DSF), which is equivalent to the BSDF but stable at directions close to grazing (ASTM International, 2019):

$$DSF(\theta_i, \phi_i, \theta_s, \phi_s) = BSDF(\theta_i, \phi_i, \theta_s, \phi_s) \times \cos\theta_s$$

Employing a tool-chain implemented in RADIANCE, a transmission model was prepared by interpolation between the distributions of scattered light for the sparse set of measured, incident directions. First, the command pabopto2bsdf approximates the distributions by a set of Gaussian "Radial Basis Functions" (RBFs), and interpolates between the measured incident directions by variation of the basis functions' parametrizations. The command bsdf2ttree then samples the interpolants at discrete resolution and builds a three-dimensional tensor. This data-cube is subsequently translated into a tree-structure by selectively merging cells where the distribution's gradient is low. The result is a compact model, later on referred to as *Model M*, of locally adaptive resolution. Since directional scattering cannot be reliably extrapolated, *Model M* is valid only in the range of measured directions $\theta_i \leq 82.5°$ and returns just the diffuse background for incident directions close to grazing.

### Acquisition of surface micro-geometry and ray-tracing to model light scattering

Light scattering by the sample, which comprises a theoretically clear, non-scattering material, is caused by refraction at the rough surfaces, which optically form the outer interfaces between a dielectric solid and air as its surrounding medium, and inclusions of air and other particles, that form internal interfaces. Employing confocal microscopy, the height reliefs of parts of the sample's front and back surfaces were prepared (Fig. 5 a and b). This should allow to relate the causal, geometric properties of the sample to its effective, optical light scattering properties.

Based on the acquired surface geometries, a second data-driven transmission model was generated. The front- and back-surfaces of the sample were tiled and arranged so that they, together with added side-surfaces, form a closed volume. All surfaces were attributed the optical properties of clear glass (refractive index 1.52). Note that this model does not account for volume scattering e.g. by bubbles or other impurities

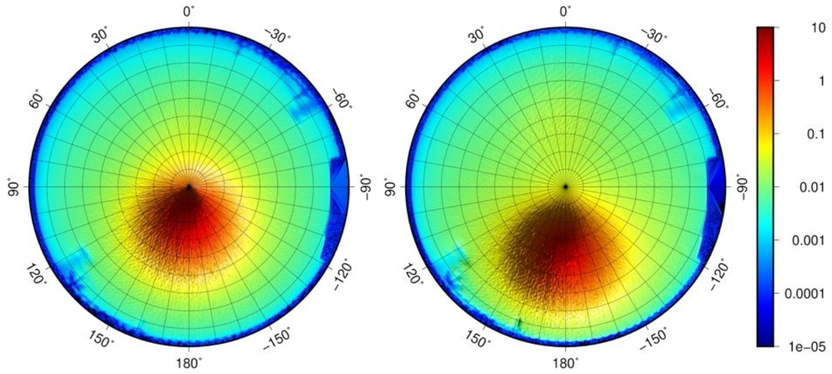



*Fig. 6. Measured DSF for incident direction $\theta_i$ = 20° (a) and 40° (b), $\phi_i$ = 0°.*

in the glass. Fig. 5 c illustrates the geometric model with opaque properties to increase readability of the surface structure.

The RADIANCE command genBSDF applies backward ray-tracing to the geometric model to solve light propagation through the sample. Adaptive data-reduction produces a computationally generated, data-driven BSDF model in analogy to the measurement-based model generation process. Other than the latter, its computational counterpart provides *Model C* that is valid for any pair of incident and outgoing directions including those close to grazing.

### Exemplary application of the models

To test the applicability of *Model M* and *Model C*, they are applied in an exemplary daylight simulation of a simplified room exposed to a sunny sky. The room model features a window of dimensions 0.80 m×1.10 m, that corresponds to a window in a villa in Pompeii (Spinazzola, 1953). Its panes are modelled as flat polygons of type BSDF in RADIANCE. All other surfaces are assumed to be opaque (reflectivity 0.70 for ceiling and wall, and 0.15 for floor and frames), and to scatter light as ideal Lambertian diffusers.

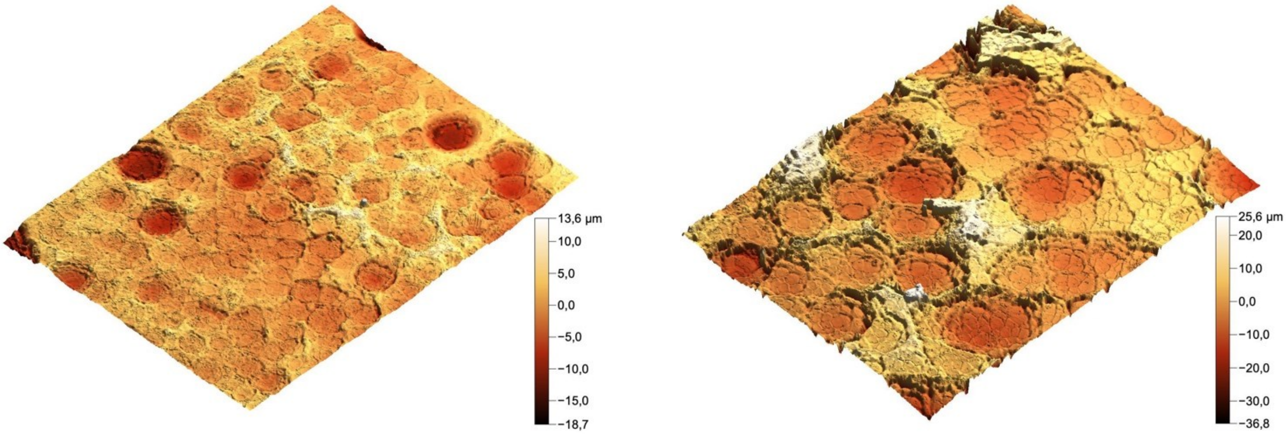
Two simulations are performed, one for each data-driven model[1]. The sun direction is orthogonal to the window-wall at an elevation of 75°. The simulation results in imagery with pixel values representing—after conversion from radiometric to photometric units—luminance $L$ [ cd/m2 ]. The luminance maps are illustrated by the application of a colour scale. In addition, illuminance $E$ [ lx ] was measured for selected locations on window, wall, floor and ceiling.

## Results and discussion

### Measured light scattering

The measured transmission distribution for two exemplary incident direction ($\theta_i = 20°$ and $40°$, $\phi_i = 0°$) is illustrated by Fig. 6. For all measured incident directions, distinct forward-scattering is observed that produces a widened peak in the hemispherical distribution. The transmitted peak is, as expected for glass with arbitrary perturbations, centred around the opposite of the incident

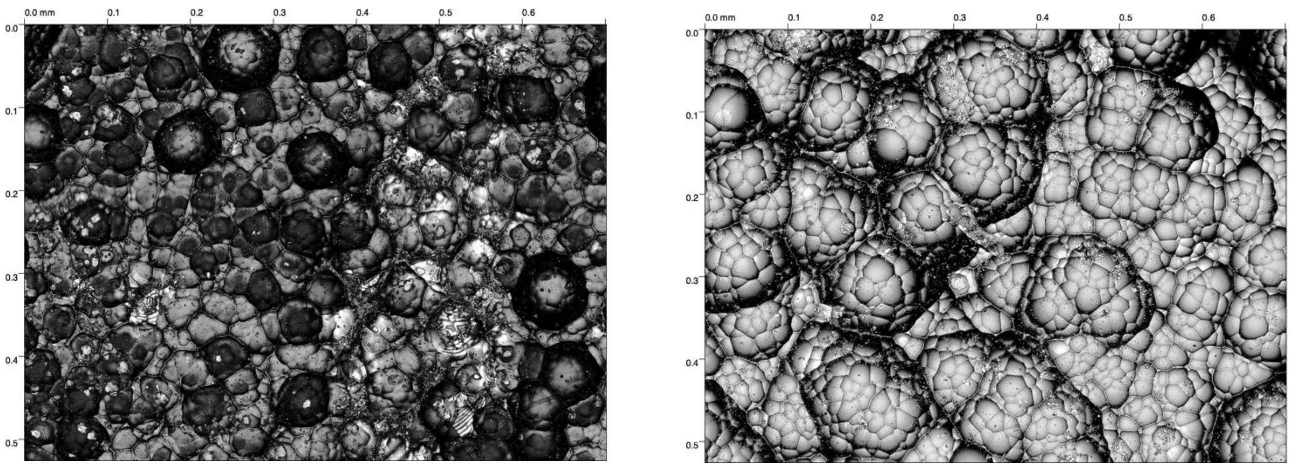
[1] Simulations were performed using the RADIANCE command rtpict with following parameters: -ss 32 (specular samples), -aa .1 (ambient accuracy), -ab 4 (ambient bounces), -ad 8192 (ambient divisions), -as 4096 (ambient super-samples), and -lw 1e-5 (limit weight).




*a* *b*

*Fig. 7. Height maps of front (a) and back (b) surfaces, acquired under monochromatic illumination by a red laser.*

direction. A region close to the sample horizon at $\phi \approx -90°$ is shaded by the vertical column holding




*a* *b*

*Fig. 8. Luminance maps of front (a) and back (b) surfaces, acquired under white illumination.*

the sample mount, and appears black in the plot. Note that the logarithmic scale, covering five decades, compresses the peak and exaggerates the background.

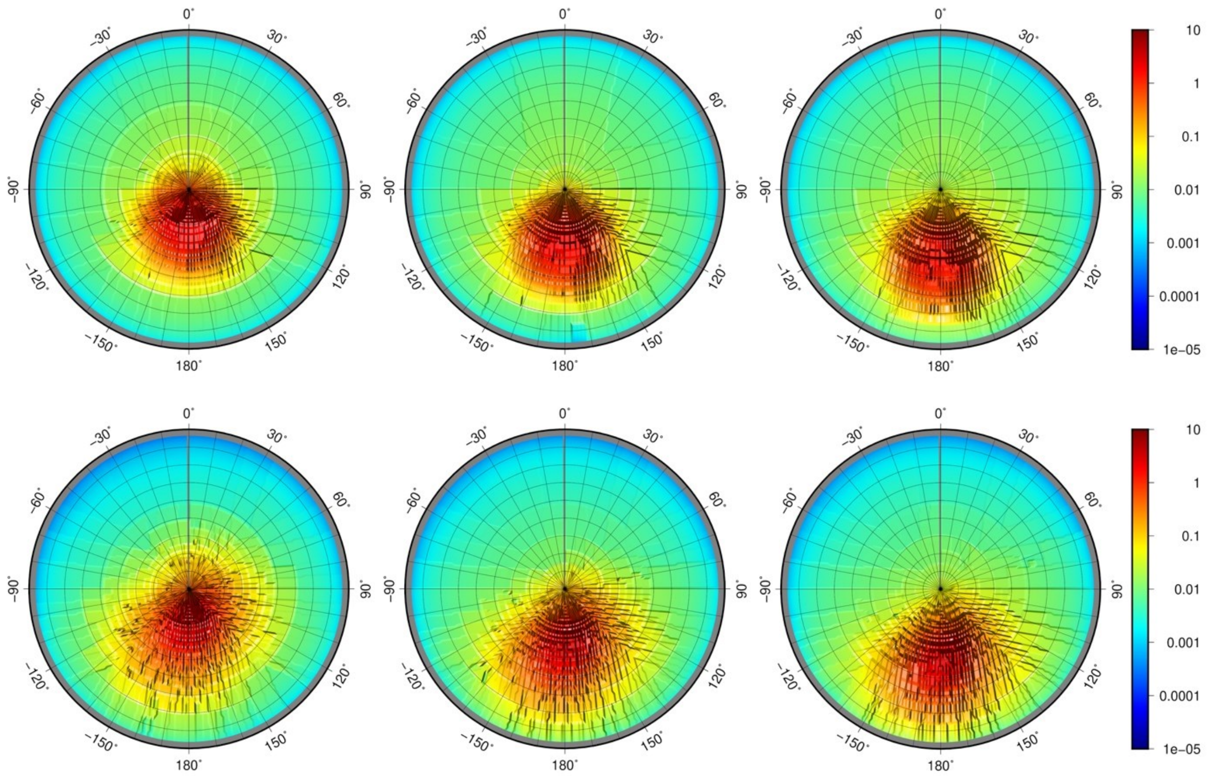
Direct-hemispherical transmission $\tau_{d-h}$ was calculated by integration of the hemispherical distributions over all scattered directions (Table 1). Reaching 0.697 under normal illumination ($\theta_i = 0°$), it decreases with increasing obliqueness of the incident direction to 0.158 ($\theta_i = 82.5°$). Results of the gonio-photometric characterisation are available as a digital data-set (Grobe and Noback, 2019).

### Surface micro-geometry of the sample

Confocal microscopy on the front and back surfaces provided two data-sets. The first data-set encodes the z-position of the focus where the pixel brightness reached its maximum, and thereby provides a height map of each surface. It is acquired under the monochromatic illumination of a red laser diode. Fig. 7 shows the reliefs of the front (a) and back (b) surfaces, with a colour map applied to the z-values. The recorded pixel elevations of the back surface cover a range of ≈ 60 µm, while those on the frontside are limited to $\approx$ 30 $\mu$m. A pattern of calderas covers the entire front and back surfaces. The surfaces within these calderas, especially on the backside, appear to be rough.

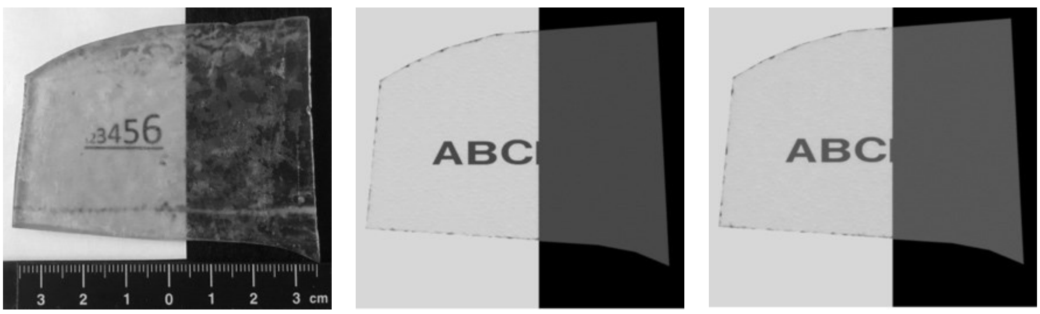
| $\theta_I$ | | 0.0° | 20.0° | 40.0° | 60.0° | 82.5° |
|---|---|---|---|---|---|---|
| $\tau_{d\text{-}h}$ | measured | 0.697 | 0.676 | 0.579 | 0.410 | 0.158 |
| | Model M | 0.715 | 0.704 | 0.590 | 0.417 | 0.137 |
| | Model C | 0.860 | 0.835 | 0.713 | 0.497 | 0.266 |

*Table 1. Measured and modelled direct-hemispherical transmission as function of the incident off-normal angle $\theta_I$.*




a b c

*Fig. 9. Plots of the DSF from Model M (top) and Model C (bottom), $\theta_I$ = 20° (a), 30° (b), and 40° (c).*




a b c

*Fig. 10. Photograph of the sample, (a) and synthetic imagery by Model M (b) and Model C (c).*

The second data-set, acquired under the illumination of a white light source, is a magnified image of the covered surface area where each pixel represents luminance as recorded so that the focus was set according to the local elevation of the surface. The resulting, sharp imagery of Fig. 8 illustrates the geometric features of the sample's front (a) and back (b) surfaces at higher resolution than the height maps.

The relief of the backside reveals a structure of clustered craters. Small secondary pits cover the entire surface and follow the surface of larger, primary calderas, causing the apparent roughness observed on the height maps. This is contrasted by the frontside, where calderas of moderate diameter are the predominant characteristic. The secondary pits are not clearly identified on the frontside.

Caldera-like structures are typical for a glass degradation mechanism referred to as pitting in literature. One possible explanation for the two types of pits on the backside could be a change of the environmental conditions affecting the backside during the process, that did not occur on the front. However, this explanation attempt is a mere hypothesis that asks for further investigation. Regardless its causes, the effective perturbation of the surface can be assumed to have a strong influence on the light scattering properties of the sample.

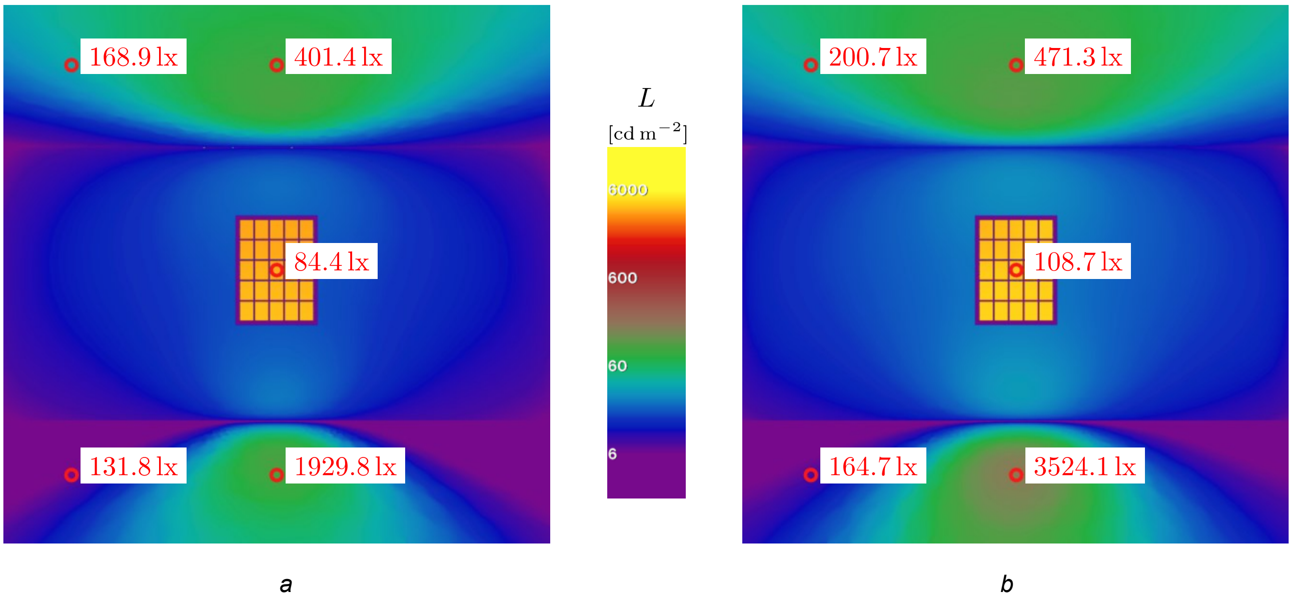



*Fig. 11. Falsecolor maps of luminance distributions, window modelled from Model M (a) and Model C (b).*

## Data-driven models of the sample

The top row of Fig. 9 shows the distributions returned by the measurement-based *Model M*. Results for three incident directions are illustrated. a) and c) represent directions that were included in the model generation ($\theta_i = 20°$ and $40°$). Consequently, only effects of fitting RBFs and the final data-reduction are expected. While a) and c) correspond to the result of the measurement illustrated by Fig. 6, the top Fig. 9 b) is the result of interpolation between the two measured directions, and predicts the distribution for an incident direction that was not part of the measurement ($\theta_i = 30°$).

The distributions predicted by the computationally generated *Model C* are illustrated in the lower row of Fig. 9. Note that no interpolation was required in the model generation process, since ray-tracing was performed for any pair of incident and outgoing direction of the initial tensor before data-reduction.

Fig. 10 shows a photograph of the sample (a) compared to *Model M* (b) and *Model C* (c), applied to a flat polygon.

The plots, as well as the imagery produced by applying the BSDF models to the sample's macro-geometry, show good overall agreement between the two data-driven scattering representations, and in a comparison between measurement or photography. As expected, local deviations of the sample from its average BSDF are not accounted for. Since the light scatter measurement as well as the modelling based on the surface's height maps did not resolve colour channels, results are photometric, not colorimetric.

### Exemplary daylight simulation

The exemplary simulation of a view towards the South window provides the imagery comprising Fig. 11, based on measurement-based *Model M* (a) and computed *Model C* (b). Four types of surfaces (window panes, floor, ceiling, wall) can be distinguished in the analysis, that receive daylight by different mechanisms. Local values of illuminance ($E$) are overlaid on top of the colour-encoded luminance maps ($L$).

Both data-driven models predict scattering of the incident sunlight that causes the window panes to light up, with luminance reaching $L \approx 5{,}500$ cd/m$^2$ through the glass panes. Illuminance on the inner side of the window is only due to inter-reflection from distant, opaque surfaces and therefore low with $E \approx 84$ lx for *Model M*, and $E \approx 109$ lx for *Model C*.

The floor is predominantly illuminated by light that is directly transmitted downward. This corresponds to the peak in the measured BSDF, that was replicated by both models. Consequently, the two synthetic images both feature a pronounced, bright region of the floor. It is significantly brighter with *Model C*. The smooth boundaries of these brighter areas are due to forward scattering that is indicated by the width of the peak in measurement and both models. Illuminance reaches values of $E \approx 1{,}930$ lx and $\approx 3{,}524$ lx for *Model M* and *Model C* respectively. The illuminance falls off toward the sides, with similar illuminance values predicated by both models ($E \approx 132$ lx and $\approx 165$ lx).

The diffuse background of the BSDF causes scattering toward the ceiling. While the luminance is higher than the floor's due to its reflectivity, the illuminance in the centre of the ceiling reaches 401 lx or 21 % of that on the floor for *Model M*, and $471$ lx or 13 % for *Model C.* The result indicates that the measurement-based model predicts a higher degree of diffuse scattering than the computational model, and agrees with the higher directional forward scattering of the latter, reflected by a significantly higher illuminance on the floor in the directly illuminated central region.

The luminance distribution on the Lambertian wall, which is directly correlated to the illuminance on the vertical surface, shows good agreement for both models. Illuminance on the inside of the window is lower for *Model M*.

## Conclusions and outlook

The examination of the glass finds revealed a pronounced structure, that resembles effects of corrosion processes. This structure covers the traces of the manufacturing process and thereby obfuscates its expected effect on the light scattering properties of late antique window glass. A method to eliminate the later deterioration from the characterisation of the glass properties is therefore needed to reconstruct its effect on the natural illumination of buildings.

Both modelling methods are applicable to represent the glass panes in their current state in RADIANCE. In an exemplary daylight simulation, both models agreed qualitatively, replicating all effects such as widened directional transmission, scattering from the illuminated glass toward the observer leading to an apparent glow of the panes, and the diffuse scattering of daylight. This agrees with the similar distributions predicted by the models for selected incident directions. The significant differences found by quantitative comparison of simulation results in terms of illuminance, which was performed for few selected positions in the image domain, revealed that computationally generated *Model C* predicts stronger directional scattering than *Model M*, based on direct BSDF measurements. It is concluded that the qualitative appearance of the glass can be sufficiently described by the computational model, which accounts only for scattering by the glass surfaces. However, to achieve quantitative agreement between both models, this is not sufficient. One possible explanation is by the impact of scattering by inclusions and bubbles in the glass, which is absent in *Model C*.

Based on this finding, only methods that account for the scattering by the glass mass are considered as viable to model the original light scattering properties of the window glass. Two modelling approaches are considered by the authors, and will be developed and tested in future research. The first relies on the direct measurement of light scattering, such as in the generation of *Model M*. However, rather than an archaeological find, replicated samples produced by the known manufacturing techniques would have to form the base of this approach to isolate the deterioration effects. The second approach employs ray-tracing on geometric models of the micro-structure, such as in the generation of *Model C*, but including the inclusions and bubbles that were not modelled in the presented research. The development of such geometric models could be guided by microscopy in analogy, but aim only at artefacts due to manufacturing rather than the direct translation of the scanned height map into a light scattering model.

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# Study for the Lighting of Four Medieval Castles in Cyprus

## Pafos, Kolossi, Limassol, Larnaka

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**Abstract:** To design the lighting study for four medieval castles in Cyprus, the impact of natural light on the castles' facades was observed and recorded. It is essential to highlight the architectural features of each castle in isolation by means of the application of differing concepts and methodology. The areas surrounding the castles are an important parameter to take into consideration when focusing on lighting enhancements: artificial light, as well as quantity and color of fixtures can be adjusted on certain days (RGB) of the year according to the schedule of the Department of Antiquities of Cyprus.

***Keywords****: Night Lighting—Monuments—Exhibition rooms—Medieval Castles—3D Design—Cultural Heritage*

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## Introduction

This project (VC/2015/0836) was funded by the European Commission DG Employment, Social Affairs and Inclusion Investment EGF, Shared Management Commission and was supervised by the Department of Antiquities of Cyprus[4].

The lighting study was carried out, after tender, by 'EON, Design and Manufacturing of Architectural and High-Quality Lighting Systems' in collaboration with the 'Ergo Culture Human Traces' co-operative.

Within the project's framework, an interim report was submitted in which lighting proposals for the castles were included. Different lighting solutions, as well as their advantages and disadvantages, were presented analytically.

Together with officials from the Department of Antiquities of Cyprus, the project team visited the medieval castles whereupon the proposed solutions were analyzed in situ. During these visits,

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solutions were also discussed as to the interior lighting of the each castle site, given that permanent and temporary exhibitions are often hosted within the castles' interior spaces.

The fundamental parameters of lighting design are: luminance (cd/m$^2$), illuminance (lux), reflectance on building materials, the color temperature of light, the compatibility of the aesthetics to the nature of the site, a comfortable optics area (reduced glare to enhance visual comfort), the protection of flora and fauna within the castle's surroundings and, finally, dimming control and low energy consumption. Led luminaires have been proposed for the illumination of interior areas as well as for the lighting of exhibition spaces.

## Methodology

The principles adhered to regarding the recording and evaluation of the parameters for the photorealistic process of the exterior facades of the castles are as follows:

1) The archaeological data for each castle and its surrounding area.
2) A description of the construction phases of the facades.
3) The environmental context surrounding each monument.
4) The current lighting conditions of the castles, their surrounding area and how each reflect on the overall image of the monument and on the visitors' perception of the monument.
5) Data collection of the color of building materials using mobile equipment and calculation of light reflectance in specific sets for specific building materials.
6) Recording of the impact of natural light on the facades and its alterations during the day through detailed descriptive comparison between shady and illuminated areas.
7) How architectural details are enhanced by means of natural light.
8) Current electricity circuits.
9) Digitalization of the ground plans and each façade separately (as provided in printed form by the Cyprus Department of Antiquities) and design of 3D models, including all the details of each façade.
10) 3D modeling of each facade according to the technical specifications of various luminaires sourced from different companies.
11) Alternative lighting solutions had been proposed until the final one was accepted by the Cyprus Department of Antiquities.
12) Re-design of electricity circuits to provide different operating modes for the luminaires.

The impact and recording of natural light on the facades is essential for the later design of artificial lighting for each castle, because in this way architectural features can be enhanced and highlighted in the way that the medieval architect had originally conceived them.

## The Castle of Pafos

The castle of Pafos stands on the ancient mole in the western part of the town's port. Its characteristics today are the result of various modifications throughout its history (Fig. 1). The Frankish rulers of the island built the castle in the middle of the 13$^{th}$ century to replace the Byzantine fort destroyed in the earthquake of 1222 A.D. When the Genoese captured the towers in 1373 A.D. they made certain modifications and also reshaped the moat.

What survives today is the 1780 Ottoman restoration of the western Frankish keep with its Venetian additions. An inscription above the sole entrance of the castle bears witness to this restoration.

On the upper level of the castle there is a battlement indented with twelve crenels, which housed a corresponding number of cannons. The Ottomans removed the cannons in 1878 when they handed over the administration of the island to the British.

From the beginning of British rule the castle was used as a salt store until 1935 when, under the Cypriot Law of Antiquities, the castle was declared an Ancient Monument. Since then, the castle has been restored and is protected by the Department of Antiquities.

**Lighting Of Exterior Façades – Photorealistic Study.**

Luminance is an important photometric parameter in our calculations, so in order to determine this feature, the lighting of the castle's surroundings and the visitors' viewing distance, as well as the architectural features of the construction need to be analyzed. Reflectance on the materials of each façade will also be taken into account.

In terms of the lighting of the surroundings, the waterfront of Pafos Castle is illuminated by fixtures mounted on poles and fitted with low pressure Na lamps. The visitors' viewing distance to the castle is considered to be somewhat close.

On the main NE façade there is a bridge connecting the waterfront to the castle's main entrance. Sea water surrounds the other two facades from 0.5 m to 1 m in height. Masonry stones are aligned in rows of both larger and smaller blocks. The main color of the stones is brownish on both the rougher and smoother surfaces while the reflectance is estimated at between 20–25 %.

According to our results, luminance and illuminance for each façade is determined as:

*North eastern (main) façade*: 2 cd/m$^2$and 25lux, RGB (3500 K) floodlights to be installed in the four contoured niches located along the waterfront, to the right and left of the bridge (Fig. 1a, 2):

Fl.b (two floodlights 1820 lm, beam angle 40$^o$, power consumption 54W)

Fl.c (two floodlights 1820 lm, beam angle 40$^o$ & 20$^o$, power consumption 54W)

Fl.d (two floodlights 1820 lm, beam angle 20$^o$ & 40$^o$, power consumption 54W)

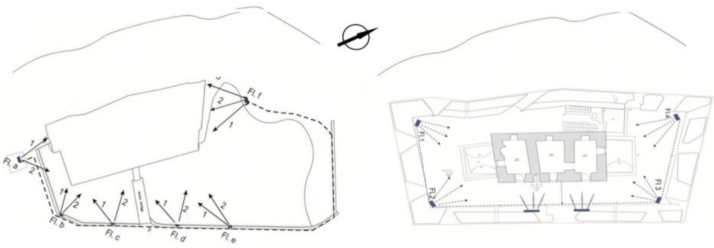
Fl.e (two floodlights 1820 lm, beam angle 20$^o$, power consumption 54W)

*North western façade:* 1.7 cd/m$^2$ and 26 lux, three RGB (3500 K) floodlights, 1820 lm, beam angle 40$^o$ and 20$^o$, power consumption 54W.

*Southeastern façade:* 1.8 cd/m$^2$ and 24 lux, two RGB (3500 K) floodlights, 1820 lm, beam angle 60$^o$ and 40$^o$, power consumption 54W.

*Keep. Tower:* The installation of four RGB (3500 K) floodlights at each corner of the terrace has been proposed to achieve lighting uniformity and consistency, while linear luminaires will also be installed at the center of the NE façade. We suggest that the lighting of the main tower be of lower intensity than the lighting of the rest of the façades (Fig. 1b, 2).

Specifications: Four RGB (3500 K) floodlights, 1820 lm, beam angle 40° and two linear led luminaires RGB (3500 K), 634 lm, beam angle 60 × 30°.



*a* *b*

*Fig. 1. Castle of Pafos from the north. Location of floodlights a) Ground plan b) The keep (© Department of Antiquities of Cyprus)*

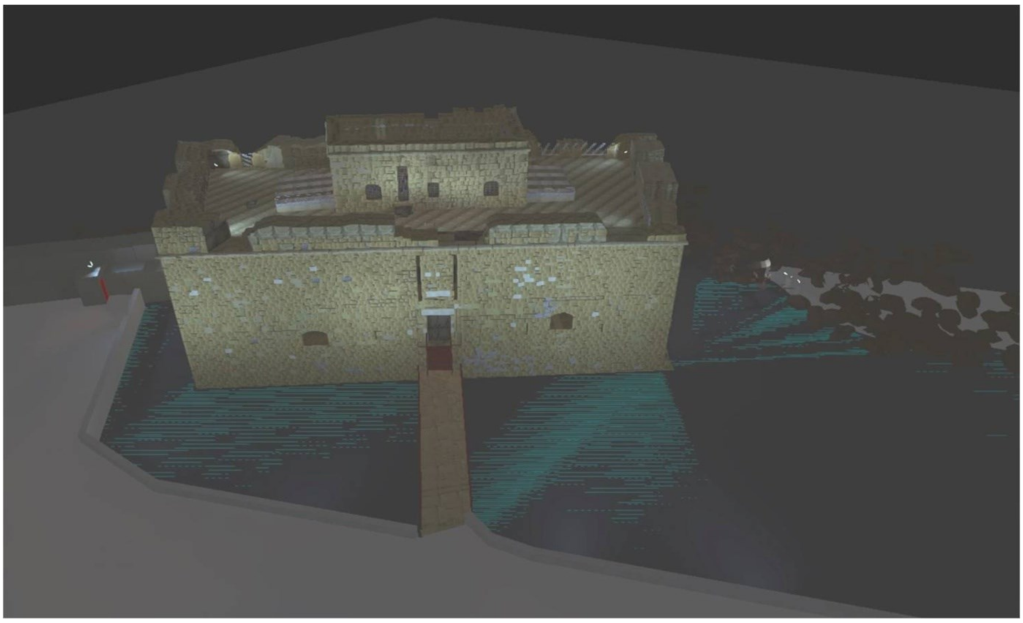


*Fig. 2. The Medieva lCastle of Pafos. Main façade and tower, 3D model (© Department of Antiquities of Cyprus)*

### Interior lighting

Entrance and five halls on the ground floor.

Six floor standing Led luminaires will be placed on the left and right-hand sides of the entrance and the halls. Indicative type LED luminaire with angle beam 40°, 3000 K, 18 W power, 1758 lm, IP67 protection degree, featuring dimmer have been proposed. The luminaire is to be mounted at the top of a 2 m-high pole.

Lighting of the halls on the ground floor.

During winter, storms can generate waves that occasionally reach the skylights, while sea spray can enter the area under the skylights. The opening in the upper part of the frame is covered with a semi-circular cover which abuts with flanges onto the frame to prevent water infiltration.

Two stainless steel frames (channels) can be installed 50 cm below the skylights. Such frames would be rectangular in shape. Twelve Led luminaires of 18 W and 3000 K each are to be placed in each frame. Ten luminaires will be adjusted at a 40° beam angle and two at a 17° beam angle (Fig. 3).

*a* *b*

*Fig. 3. Medieval Castle of Pafos. a) Interior areas under the skylight b) Metallic frame with luminaires under the skylight, schematic display (© Department of Antiquities of Cyprus)*

## The Castle of Kolossi

The castle of Kolossi is one of the most important extant fortifications of the island’s Frankish period and is located at the southern edge of the village of Kolossi, about 11 km west of Limassol (Fig. 4a). The castle was built in 1210 by the Order of St. John of Jerusalem (Knights Hospitaller). In 1306 it briefly came into the possession of the Knights Templar, who were supporters of Amalrique of Tyre, the usurper to the throne. After the abolition of the Knights Templar in 1313, the castle of Kolossi returned to the stewardship of the Knights Hospitaller, but was destroyed during the Mameluke raids in 1525–26. The Great Commander Louis de Magnac built the existing castle upon the ruins of the 13$^{th}$ century castle. Magnac’s coat of arms can be seen alongside the emblems of Jerusalem, Cyprus and Armenia, as well as the old Lusignan coat of arms, carved into the outside of the eastern wall of the castle and on a fresco on the interior wall of the second floor.

**Lighting of exterior façades – Photorealistic study**

There are similarities between the façades in terms of stone color, roughness, joints and apertures. All the façades were constructed using polished grey stones, except for the upper sections of the western and northern façade, where weathering has turned the color to graphite.

An important architectural feature in the eastern façade is Louis de Magnac's coat of arms along with that of the Kingdom of Cyprus. Five 'murder holes' (meurtrières) are located at the top of the southern façade just above the castle entrance.


*a* *b*

*Fig. 4. a) Medieval castle at Kolossi, view from SE, b) ground plan and location of floodlights (© Department of Antiquities of Cyprus)*

The current electricity network can be used and further improved in the new lighting study (Fig. 4b). However, new floodlights will need to be installed closer to the monument to allow for: a) improved visibility and enhancement of the building, b) a selection of floodlights with low energy consumption, c) the protection of flora and fauna.

The illumination of the castle's surroundings, including pathways for visitors, the ruins and the old acacia tree can be enhanced by means of softer lighting options.

*Eastern façade:* A 3–4 m high wall segment, which probably dates to the castle's initial phases of construction, is located at the eastern edge of the façade. Visitors pass along a pathway, located between the wall and the façade, to the castle's eastern areas (Fig. 4b, 5a), thus limiting the use of floodlights along the pathway. However, a series of linear ground luminaries would provide a solution, illuminating the façade's lower sections as far as the coat of arms. Consequently, supplementary lighting will be needed for the upper sections of the façade, for which we propose the installation of pole-mounted floodlights at a distance from the façade, to effect both the enhancement of architectural features and to minimize visual impact on visitors.

The average reflection coefficient ≅ 35 %, luminance ≅ 2 cd/m$^2$, illuminance ≅ 20 lux.

Lighting of the lower section using linear RGB luminaires.

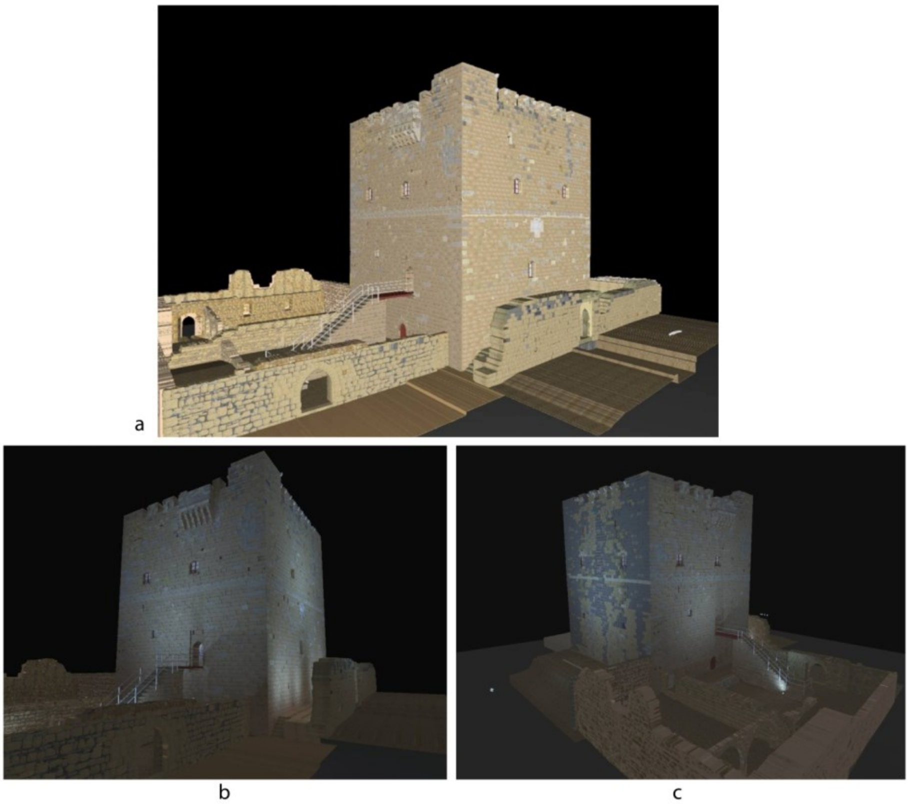


*Fig. 5. a) Medieval castle at Kolossi, 3D model, view from SE b) View from SE, photo realistic model, c) View from SW, photo realistic model (© Department of Antiquities of Cyprus)*

The eastern façade will be partially illuminated as far as the coat of arms by means of linear luminaires. These luminaires will be fixed with brackets onto metallic bases (ground installation) and can be rotated through their horizontal axes.

To achieve optimal results in lighting distribution and uniformity, remotely controlled luminaires featuring a wide beam angle and dimming capability have been recommended.

3D computer software lighting tests were conducted and luminaires with the following technical specifications have been recommended: five linear with 12 leds, 4000 K, beam angle 12 × 44°, 628 lm.

Lighting of upper section of the façade using RGB floodlights.

The middle section of the façade extending to the battlements will be illuminated by floodlights mounted along a horizontal arm on a 3 m high pole positioned 15 m from the castle. This pole will be erected closer to the surrounding shrubs.

*Eastern façade location a:* Four RGBW- three floodlights1820 lm at 40° and one 1846 lm at 20° Power consumption 54 W (Fig. 4b, 5b).

*Southern façade:* Potential location for floodlights: a) on the left and right wing of the entrance landing and b) in the masonry cornices located opposite the façade and which date to the castle's initial phases of construction.

Average reflectance ≅ 35 %, luminance ≅ 2 cd/m$^2$, illuminance ≅ 20 lux.

The floodlights will be installed on grounded metallic bases to avoid visual interference. Specifically:

Location b: single RGBW floodlight, 1846 lm, beam angle 20°, power consumption 54 W.

Location c: single RGBW floodlight, 1819 lm, beam angle 40°, power consumption 54 W.

Location d and e: two single RGBW floodlights, 1819 lm and 1846 lm respectively, power consumption 54W.

*Western façade:* The only potential location is the area along the stone enclosure where the existing floodlights are installed. These cannot be installed closer to the monument due to ongoing excavation (Fig. 4b, 5c).

Average reflectance ≅ 25 %, luminance ≅ 1.8 cd/m$^2$, illuminance ≅ 23 lux.

Location f: Four RGBW floodlights—1819 lm, beam angle 40°, Power consumption 54 W.

Northern façade**:** floodlights will be mounted on a metallic 'Π' shaped frame 10 m from the façade.

Average reflectance ≅ 25 %, luminance ≅ 1.8 cd/m$^2$, illuminance ≅ 23lux.

Location g: four RGBW floodlights—1819 lm -beam angle 40°-Power consumption 54 W.

### Lighting of the interior halls

To light the interior of the castle, floor standing luminaries have been recommended (base, square sectioned pole, led lamp, 2 m high). Three luminaries are to be installed in each hall, apart from the ground floor, where a single luminaire in each hall will suffice. The floor standing luminaries are to remain switched on until later in the day. Given the fact that the night lighting will gradually decrease in intensity towards the upper sections and battlements, the visitor will be able to see the illuminated windows in addition to the illuminated façades. These luminaries can be switched off using a timer. Indicative type LED luminaries with wide beam angle 40°, 3000 K, 18 W, 1758 lm, IP67 protection degree.

### LIGHTING OF pathways and surrounding area

Despite ample illumination of the castle façades, their reflective capability will not be sufficient to illuminate the surrounding area. Furthermore, the ongoing archaeological excavation area must be illuminated for health and safety reasons when the monument is open to the public at night. For this reason, our lighting solutions will provide an adequate lighting environment for visitors without having a negative impact on the overall lighting of the castle (Fig. 4b). Indicative oval light brass wall turtle with metal wire guard: Socket E27 where Led lamp is affixed, spherical matte color lamp, power 5 W, 3000 K, diffused light without causing glare, installation of constructed niches in walls with dimensions of at least twice the size of each luminaire.

## The Castle of Larnaka

According to written sources the castle of Larnaka was built during the reign of King James I (1382–1398). These sources mention that the Castle was constructed to protect the town's harbor, which, after the capture of Famagusta, was used as the island's main port. In its present state of conservation the castle consists of a complex of buildings constructed over different historical periods. The two-storey building on the north side was constructed during the Ottoman occupation, evidenced by its architectural style and a Turkish inscription above the entrance, while the eastern and southern wings date from earlier phases of the castle's construction. The British Administration used the western chamber in the eastern section of the ground floor for the execution of convicts. The gallows, which must have been located in the room, were in use until 1948. Today the Castle houses a small museum consisting of three rooms situated on the upper floor of the main building (Fig. 6a).

### Lighting of exterior façades – Photorealistic study

Due to the overlapping construction phases of the castle, each façade features different architectural details.

As a result, the reflection coefficients vary. Very few stones share similar levels of reflectance. Consequently, different coefficients have been calculated for each façade: 31 % for the northern façade, 40 % for the western, 34 % for the southern and 25 % for the eastern.

According to our results, RGB (3500 K) remote control operated luminaires have been suggested.

To estimate luminance levels, the lighting of the castle's surroundings, as well as the visitor viewing distance were considered. The area located opposite the northern and southern façade is illuminated by street lighting luminaires, whereas the area around the western and eastern façade is totally unlit.

The luminance and illuminance for each façade was estimated as:

*Northern façade*: 1.8 cd/$m^2$and 20 lux.

*Western façade*: 1.7 cd/$m^2$and 17 lux.

*Southern façade*: 2 cd/$m^2$ and 22 lux.

*Eastern façade*: 2 cd/$m^2$ and 22 lux in the higher sections and 17 lux in the lower sections.

Northern façade.

Mounted RGB (3500 K) floodlights on poles will be installed at fixed positions along the sidewalk opposite the façade (Fig. 6b). This solution can only be implemented in a specific area from the main entrance up to the northwestern corner, owing to the fact that a section of the sidewalk is located opposite the street junction and the palm-lined patio. The only place where the poles can be installed is in the section of the sidewalk located opposite the entrance extending to the castle's northwestern corner. There is already an installed pole in this section. The floodlights are to be located between 15 m and 23 m from the northern façade.

Technical floodlight specifications: four RGB (3500 K) floodlights, 1820 lm and 1791 lm, power consumption 54W, beam angle three at 20° and one at 40°.


a

Fig. 6. a) Medieval Castle at Larnaka, view from NE, b) View from SE, photo realistic model (© Department of Antiquities of Cyprus)

Western façade.

Three poles can be installed with three floodlights on each.  The poles should not be the same shape as the existing ones on the northern façade and should not be higher than 3.5 m. If the floodlights are installed above 3.5 m, their light beam might enter the interior yard and cause interference for visitors.

*Technical floodlight specifications:* a total of six RGB (3500 K), two floodlights on each pole, 1820 lm, beam angle 40°, power consumption 54W.

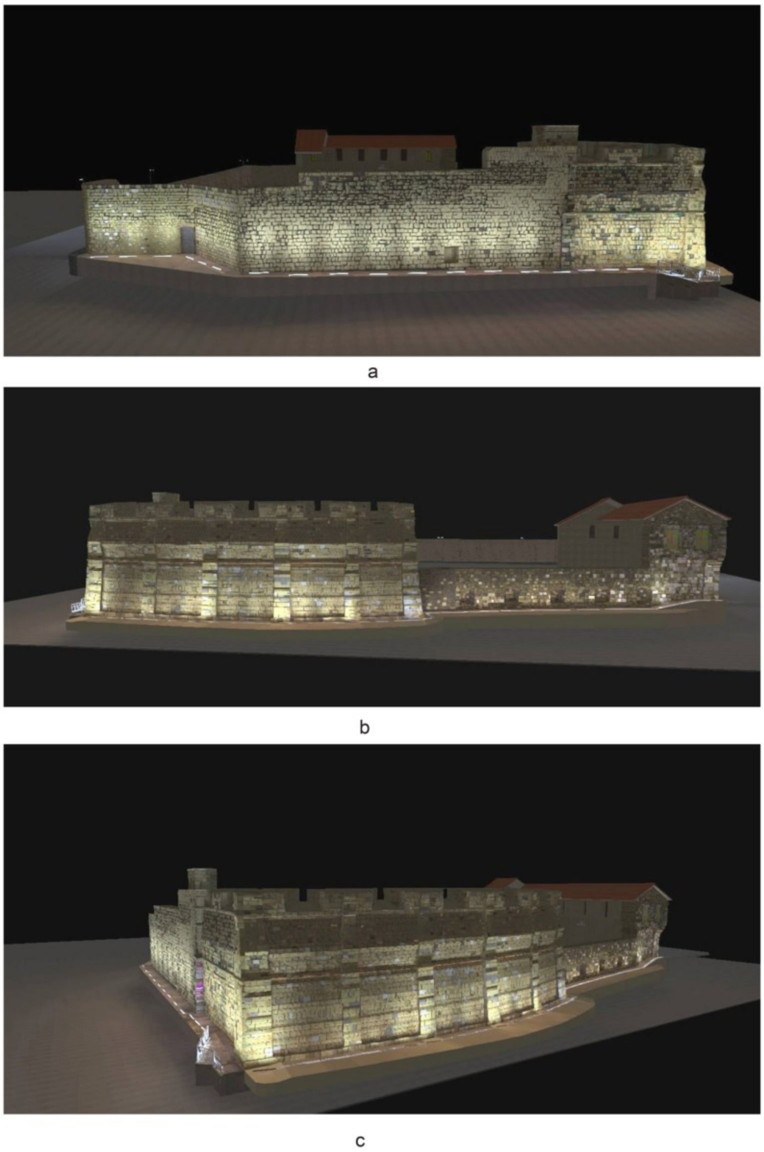


Fig. 7. *Medieval Castle at Larnaka, 3D photo realistic model a) View from south, b) View from east, c) View from SE (© Department of Antiquities of Cyprus)*

Southern façade.

Installation of linear luminaires for the lighting of the southern façade:

A continuous concrete channel 0.40 m wide and 0.30 m deep will have to be constructed along the façade. The concrete channel should be waterproofed and covered with transparent anti-slip glass (Fig. 7a-c).

If the proposed luminaires are installed on the metal ramp located at the SE corner of the sidewalk, then light will be directed sideways and away from the fortification. The railing could be positioned on the front side of the ramp and the concrete channel could either be constructed horizontally to the edge of the ramp or at the edge of the ramp below the railing.

Total number of asymmetric beam linear luminaries: 19 luminaries of 1230cm, 48leds of 2236 lm, 57W power and three of 930 mm, 36leds, 1677 lm, 44W power, IP67, IK08.

Eastern façade.

A continuous concrete channel 0.40 m wide and 0.30 m deep will need to be constructed along the façade. This concrete channel should be waterproofed and covered by transparent anti-slip glass. In the event of water running along the channel, plastic tubes can be used for drainage. In addition, Φ100 tubes can also be fitted to provide proper ventilation within the channel and prevent condensation on the underside of the glass. A third tube (Φ60) can be also placed in the middle of each concrete channel to improve air circulation.

A small ramp is located at the NE corner of the sidewalk. Luminaires are currently installed in the middle of the ramp. If the same inclination to the luminaries is maintained, (i.e. that of the ramp) then both the fortification and the façade will only be partially illuminated. For this reason, the width of the ramp should be increased to 0.50 m with the concrete channel constructed along its edge on two or three horizontal levels, although the glass cover to the channel can be inclined at the same angle as the ramp.

The linear luminaires on the eastern façade facing the sea are separated into two groups. The first group are those which will illuminate the lower section up to the midpoint of the facade, while the second group are those which will illuminate the upper section, including the buttress (Fig. 7b–c).

Group A.

Three RGBW linear luminaires with asymmetrical beam (length 930cm, 1700 lm) will be installed in the ramp section and twelve asymmetrical beams (length630cm, 1100 lm) will be installed between the end of the ramp and the end of the section.

Group B.

RGBW linear luminaires with asymmetrical beam have been suggested. One (length 1250cm, 2250 lm) will be installed in front of each of the six buttresses and two (length 930cm, 700 lm) along the space formed between the buttresses.

It has been also recommended that the luminaires should feature dimming control and that they should be able to be rotated relative to their longitudinal axes.

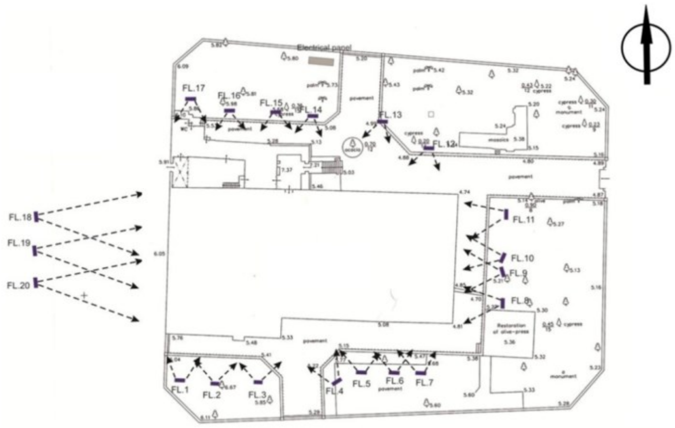
## The Castle of Limassol

The medieval castle is located near the old harbor in the historical center of the city and houses the Medieval Collection of Cyprus Museum.

Archaeological research has revealed that the castle was built over an Early Christian basilica and a Middle Byzantine structure. Other finds beneath the Castle bear witness to the existence of an important church, possibly the city’s first cathedral. According to Etienne Lusignan, the original castle was erected by Guy de Lusignian in 1193.

From the 1950s the castle of Limassol was ceded to the Department of Antiquities and used as the District Museum (Fig. 8).

*a* *b*




*c*

*Fig. 8. Medieval Castle of Limassol, a) View from east, b) View from NW c) Ground plan, position of floodlights (© Department of Antiquities of Cyprus)*

**LIGHTING DISTRIBUTION, PHOTOREALISTIC STUDY.**

To estimate the luminance, the lighting of the castle's surrounding area as well as the visitor viewing distance was considered and measured. The surrounding area is heavily illuminated. The visitor viewing distance is considered to be somewhat close.

Luminance and illuminance for each façade is as follows:

*Eastern façade*: Average reflectance 35 %, luminance 1.8 cd/m$^2$, illuminance 20lux.

*Southern façade*: Average reflectance 35 %, luminance 1.8 cd/m$^2$, illuminance 20lux.

*Northern façade*: Average reflectance 35 %, luminance 1.8 cd/m$^2$, illuminance 20lux.

*Western façade*: Average reflectance 35 %, luminance 1.8 cd/m$^2$, illuminance 20lux.

Eastern façade.

RGBW floodlights will be installed 8 m away from the eastern façade (Fig. 8):

- Three floodlights 1791 lm, beam angle 60°, power consumption 54W.
- One floodlight1819 lm, beam angle 40°, power consumption 54W.

Southern façade.

RGBW floodlights will be installed 8 m away from the southern façade:

- Seven RGBW, 1791 lm, beam angle 60°, power consumption 54W.

Western façade.

On the western façade, the existing luminaires around the pedestrian zone should be removed (especially the three that are closest to the façade). The western façade can be illuminated by means of monochromatic floodlights installed in the upper section of the 'Charoupomilos' building located opposite the façade.

- Three RGBW floodlights, 2141 lm, beam angle 21°, power consumption 50W.

Northern façade.

The northern façade is not a unified surface. Stone stairs leading up to the entrance as well as the entrance area, the ticket office and the utility room/public conveniences are all located in the middle of the façade. Under night lighting, these buildings cast shadows on the façade and, as a result, distort its architectural features. Therefore (Fig. 9):

a) lighting of the section between the NE corner and the entrance will require RGBW(4000 K) floodlights (positioned 8 m from the façade); b) installation of linear RGBW luminaires on the ticket office terrace to illuminate the section above the ticket office; c) installation of two floor standing monochromatic light led luminaires to the left and right of the entrance; d) installation of two linear RGBW luminaires on the wall behind the public convenience (the wall along the length of the utility room), e) lighting of the buildings (stairs, entrance area, utility area, public convenience) using low intensity RGBW floodlights installed close to the existing floodlights' positions.

NE section and buildings.

RGBW floodlights can be installed in the current floodlights' positions as required:

Five floodlights,1791 lm, beam angle 60°, power consumption 53W and one floodlight 1819 lm, beam angle 40°,power consumption 54W.

Section above the buildings.

Very small linear luminaires would have to be used due to limited space. The luminaires are to be fixed on bases and can be rotated on their horizontal axes. The following luminaires have been proposed in the study, taking into consideration the limitations noted above:

Two Led RGBW (432cm) to be installed on the ticket office roof and two along the utility room wall (behind the ticket office). Type of luminaires: linear with 12Leds, beam angle 12X44°, 628 lm, power consumption 17W.

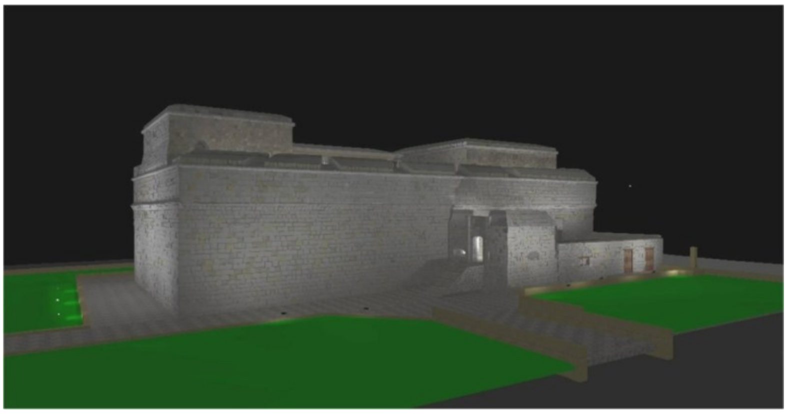


*Fig. 9. Medieval Castle at Limassol. 3D photo realistic model, view from north (© Department of Antiquities of Cyprus)*

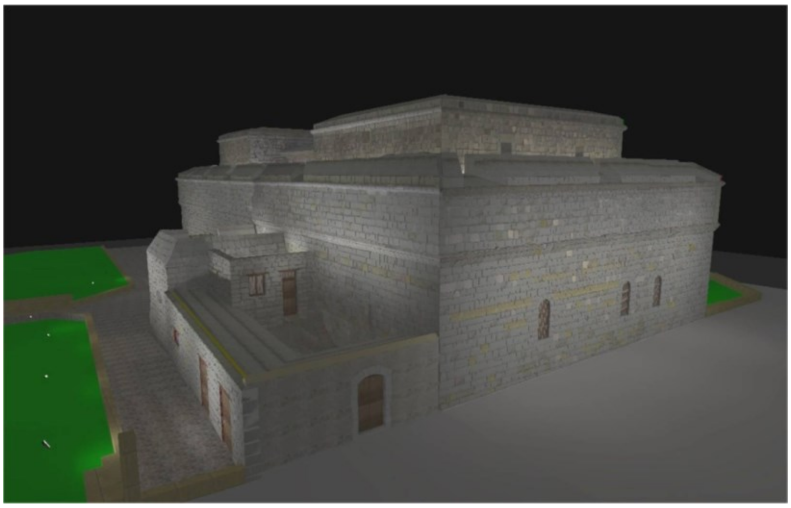


*Fig. 10. Medieval Castle at Limassol. 3D photo realistic model, view from NW (© Department of Antiquities of Cyprus)*

**Lighting of the terrace**

Lighting of the towers and battlements.

Both of the tower's façades and the terrace will be illuminated using linear monochromatic luminaires 3000 K (Fig. 9, 10). These luminaires are to be installed in the base of the skylight (northern and southern side) and around the corner between the terrace floor and the parapet. The luminaires are to be fixed on 20cm-high metallic bases and will feature a pivotal arm support on their horizontal axis. Power cables are to be fitted within protective tubing fixed to the corners of the terrace.

a. Northern and southern sides, along the skylight

Four linear luminaires with 48leds, 3000 K, 3425 lm, beam angle 32°, power consumption 52W.

b. Circumferentially at the corners of the towers and the battlements. Eighteen linear luminaires with 12Leds, 3000 K, 56 lm, beam angle 32°, power consumption 15W.

**Lighting of rooms and interior halls**

a. Lighting of the interior section of the entrance.

Currently, the interior section of the entrance is illuminated by means of a wheel-shaped fixture featuring mignon type lamps. The lighting of the area can be improved with the installation of a square metallic frame. The frame is 1 × 1 and can be mounted on the ceiling a wire rope and pulley system for easy maintenance. To light the hall, rail spot led luminaires can be used. These luminaires will feature barn door framing and dimmers and a light color of 4000 K neutral white. Both the frames and the luminaires will be colored matte grey. Eight luminaires will be installed, three with narrow beam (12°) and five with medium beam (25°).

b. Lighting of the large western hall**.**

There are museum exhibits both inside and outside the showcases in this hall. The existing luminaires are mounted on masonry and feature energy saving fluorescent lamps. This solution causes serious glare issues.

We have suggested that all fluorescent lamps should be removed while three 3000 K floor standing led luminaires should be installed on 2 m poles in the corners of the hall.

Description: small led floodlights with medium beam angle 30°, 3000 K, power consumption 50W-3960 lm, protection degree IP67. Antiglare mask to be fitted on the luminaires, which will also feature pivotal arm supports on their horizontal and vertical axes.

## Supplementary notes and Conclusion.

The project for the night lighting of four medieval castles in Cyprus was an initiative of the Cyprus Department of Antiquities and was funded by the European Commission. The design of the final proposal was shaped after several meetings and field visits with officials of the Department of Antiquities and after full evaluation of all the parameters of the study. Upon completion of the first phase of the project, a meeting between the relevant parties was held, during which all possible night lighting solutions were examined and analyzed in line with international standards on illumination. Afterwards, the interim report was submitted and upon the project's completion the final proposals were presented to officials of the ministries and municipalities concerned during a public presentation in Nicosia.  The current paper was based on the final report which was accepted and approved by European Commission and the Cyprus Department of Antiquities. The framework of the paper's publication focused on the analysis and description of all the elements concerned with the topic of the lighting of the sites, and any problems which arose therefrom, on the final presentation of photo technical results and the 3D models, in order to provide a clear picture of the results.

In conclusion the dynamic of the lighting proposal is focused on the following factors:

a) since archaeological museums are housed within the castles, the possibility of multiple remote controlled lighting choices depending on the theme of events planned by the Cyprus Department of Antiquities,

b) option for dimming control depending on the time of day and time of year,

c) new underground electrical installations and electrical wiring,

d) the final lighting proposal was based on the latest technology in contemporary luminaires and their accessible operation manuals,

e) easy and low cost maintenance of luminaires. The innovation in the current lighting study relies on the fact that the architectural features of the medieval castles are not distorted by artificial, a common issue when night lighting solutions are applied to such historical sites. The visitor, who is the final end user and judge of the results, is presented with an almost identical image of the monument during the night as they are during the day.

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# Divine Shine. Light in eighteenth-century religious architecture: Spain, Mexico and the Philippines

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**Abstract:** Light can be considered one of the key elements in the history of architecture, although technical limitations have made its analysis difficult until recently. It is now time to address how early modern architects dealt with luminescence by creating differentiated spaces. More specifically, this paper aims to prove that religious structures built in cities under Spanish rule during the eighteenth century in Europe, the Americas and Asia replicated a clear pattern. To prove this preliminarily, significant examples have been selected from different countries. Four are from Spain: (1) San Luis de los Franceses, (2) San Jacinto, (3) San Pablo (Seville) and (4) Cadiz's Cathedral. One is from Mexico: (5) the Basilica de Guadalupe. Finally, one is from Manila in the Philippines: (6) the city's eighteenth-century cathedral. Some of these structures are not preserved or have been drastically altered, requiring them to be reconstructed. Given the methodological challenges, tools including CAD modeling, terrestrial laser scanning, and photogrammetric instruments have been employed and their results compared. Afterwards, results have been analysed with specific software, such as Relux for 3D objects and Dialux for CAD models. Initial results demonstrate that there was a pattern of lighting maintained on different continents, even when contemporary treatises and contracts rarely addressed this topic. The presbytery is usually dark compared with the light of the nave and the choir. Along the same line, walls are not illuminated, thus highlighting the central space. Finally, it is noteworthy that sunlight is avoided in favor of a more homogenous solution.

***Keywords:*** *Light simulation—Digital architectural history—Early Modern—18th century—Religious architecture*

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## Introduction

The history of early modern architecture has usually emphasized the importance of light in its development, especially in churches (Riegl, 1908, p. 195; Bonet Correa, 1978; Blunt, 1979; Levy, 2004). Probably based on Biblical sources, light was understood as a representation of God (1 John 1:5), as well as an architectural tool to create space, just as painting was developing as a medium. Therefore, many churches were organised to place the better-illuminated areas at the presbytery, where the presence of God existed. At first, light was used as a rhythmical resource, to highlight some areas and perspectives (Riegl, 1908, p. 195), but from the seventeenth century onward, a new range of possibilities seems to appear. The development of dramatic techniques also affected the religious space and light became an awe-inspiring resource to get the faithful's attention, as Blunt (1979, pp. 23–24) already emphasized in Borromini's case, even without the possibility of proving it using digital analysis. In addition to bathing some parts of the interior with light, it was required to highlight tiny ornamental elements. A good example of this, still little studied, is a hidden window in a tabernacle designed by Pozzo in the Gesù Church in Rome. Light reflected onto the halo of the saint and from there to the surrounding mirrors creates a surprising effect (Levy, 2004, pp. 170). To achieve this, previously bright Renaissance churches needed to have reduced their interior lighting to underscore such an impact. At this point, it seems probable that every architectural tradition explored different options (Fabri, 2008; Poppe, 2008), including the possibilities of artificial light sources. Spanish Baroque interiors put forth a different space when compared with previous ones (Bonet Correa, 1978; Luengo, 2016; Luengo Gutiérrez and Luengo Gutiérrez, 2019). As has been traditionally understood, sunlight emphasized the nave, while the main altar remained dark, creating a "cave effect". Such innovations were parallel to their expansion and consolidation, first in the Americas and later in the Philippines, creating a culturally globalised scenario. Traditional historiographical interest on light has been based on subjective approaches (Riegl, 1908; Bonet Correa, 1978; Blunt, 1979; Levy, 2004), due to the lack of analytical tools that are now available. In recent years, some efforts have allowed us to reconstruct destroyed structures digitally and to survey preserved ones in each of these three countries, permitting a digital analysis from light simulations (Almodovar-Melendo; Cabeza-Lainez and Rodríguez-Cunill, 2018; Luengo, 2019). In parallel, a few scholars have worked on the topic for other chronological and geographical frameworks with significant successes (Moullou et al., 2012; Moullou et al., 2015; Papadopoulous, 2017), which stresses the possibilities of these techniques enriching traditional discussions on architecture's evolution. This growing academic field requires more digital examples, including both natural and artificial light simulation, to uncover diverse spatial solutions.

## Objective

This paper aims to define the particularities of the Spanish religious interior in terms of sunlight, initially through the use of candles, according to the experiences of Moullou et al (2015). Additionally, the methodological aspect is also relevant. Thus, different technical approaches will be compared in the results to find the most accurate or least costly option. Until now, the afore-mentioned papers carried out their analyses using local data collections or manual reconstructions based on measurements. In these latter cases, architectural volumes were reproduced, simplifying the remaining decorative elements, mostly included in the church design from the beginning. To do this, a selection of eighteenth-century churches has been made, including four in Spain: (1) San Luis de los Franceses, (2) San Jacinto, (3) Seville's San Pablo and (4) Cadiz's Cathedral; one in Mexico: (5) the Basilica de Guadalupe; and one in Manila, the Philippines: (6) the city's eighteenth-century cathedral. Although located on different continents, Seville and Cadiz are at a similar latitude (N37°22'58.19", N36° 31′ 48″ respectively), while Mexico and Manila are closer to the equator (N19° 29′ 52″ and N14° 36′ 2″). Despite this difference, and its effect on sun incidence, the results are not expected to differ drastically. With this in mind, and remembering that the correspondent Pre-Hispanic religious traditions are different, it would be clear that it is an attempt at Western artistic uniformity. Digital reconstruction has been obtained using different methods for purposes of comparison. Some have been carried out using a RTC360 laser scanner (1 and 3); one using close-range photogrammetry (2) (see Fig. 1), while the final two were manually reconstructed (4, 5 and 6) (see Fig. 2 and 3), due to some changes in the building or its complete destruction. Although the details obtained, and the time required are not the same, this paper aims to discuss if these three options are enough to arrive at basic conclusions and which relevant differences have been found.

The selection demonstrates a significant range, covering the issue both geographically and chronologically, but several problems arise. Some of these structures were not preserved or were drastically altered, especially in lighting terms. Furthermore, the intent of this research was demonstrating that the building was planned to maintain a uniform lighting pattern throughout the entire year, not focusing only on particular dates. For this reason, an empirical approach was avoided, and a digital simulation preferred. To compare the quality of the results, different digitalization process were employed.

## Methodology

The current status of the particular church determined the methodological approach. The easiest option was an analysis through a CAD reconstruction. This was used in Manila's cathedral, which is not preserved except for historical plans and several descriptions, where references to ornamentation are rare. Although most data was available in historical studies (Luengo, 2019), some aspects, such as the measurements of the windows, were taken from those included in the façade, relying on architectural coherence. Such decisions, in addition to the doubts about the possible differences between the project and the final structure, weaken the results' reliability. The Basilica of Guadalupe in Mexico City still exists, but this investigation has not yet been able to gain access to a digitalization of the building, thus requiring its manual reconstruction, similar to that made for Manila. The Cadiz Cathedral exhibits a more complex situation. Although the building is still in use, the building process was very complex, especially the lighting aspects, which changed at various stages during the building process. For this reason, a similar approach was chosen. An initial reconstruction was carried out using the information available in historical plans and descriptions. A second reconstruction was done, taking data from a contemporary wood model still preserved. In all these cases, based on CAD approaches, buildings are simplified, not including, for instance, tabernacles, artworks, platforms, pipe organs, or choir stalls. They may affect the results, but the information as to their historical locations, being time consuming to reconstruct, led them to not be included in this examination. These CAD models were analyses with Dialux due to its possibilities in designing complex architectural spaces. Material properties were not assigned to surfaces because most of them were about 50 % reflection factor, not affecting significantly final results. Soltice and equinox both at midday and early morning, when masses took place, were included in the process.

The other churches are well preserved in Seville. Although they have been modified, it is easy to undo these changes digitally. Thereafter, a digitalization process was initiated using photogrammetry and three-dimensional scanning. The first technique was applied to San Jacinto, because unfortunately most of its decorations have disappeared, making the effort easier. The three-dimensional file was converted into OBJ to be later analysed with Relux. This software is better prepared to deal with such files, which are not accepted by Dialux. As can be seen in Fig. 1, in addition to the data on the common spaces, which may be similar in detail when compared with other approaches, analysing the church with all its ornamentation allows us to understand its illumination in a more complex manner. After this milestone, the two remaining examples were addressed. In contrast to the characteristics of San Jacinto, San Pablo and San Luis de los Franceses are complex buildings with a full ornamentation program still preserved. This complex scenario may provide very interesting results but necessitated a different instrument. For them, a Leica RTC360 scanner was used, digitizing the interior only. The file included an immense amount of detail, even when some surfaces on the top parts of the edifice were not recorded. This signifies a large number of geometrical facades, making a subsequent digital processing with the afore-mentioned software impossible. Thus, the original file was simplified, removing data on textures and reducing the level of detail until a minimally viable reconstruction was accomplished. The file was reduced under 64000 faces, confirming that space was still recognizable.

In addition to this equipment, it is important to note that the analysis was based on simulations for the winter and summer equinoxes in the mornings. It was taken for granted that no coloured windows were included, because coloured windows were uncommon after Gothic architecture went into decline, at least according to the examples preserved. Considering liturgical uses of the time, attempts between 9am and 12 noon were included, this being the time of day in which both choir and major masses were celebrated in churches. Moreover, adjacent buildings were not considered in any instance. Although the lack of tall structures nearby is clear in historical sources in most cases (1, 2, 4 and 5), it is difficult to prove for all examples.

## Results

Regardless of the method used, the results obtained do not differ significantly. San Pablo (1690–1709) and San Jacinto (1730–1774) in Seville were both Dominican convents renovated or designed by Figueroa in the eighteenth century. They represent the typical example, where the presbytery and the lateral naves are consciously darkened in favour of the central one. At the same time, the upper part of the building, especially the vaults, are brighter. Most of the building remains under 250 lux, what signifies a satisfactory context for the preservation of paintings and gilded tabernacles. One of the members of this architectural dynasty also built San Luis de los Franceses (1699–1730). While San Pablo and San Jacinto are large three-naved churches, San Luis de los Franceses reflects a Greek floorplan. The general results by Almodovar, Cabeza and Rodriguez (2018), confirmed by this study using a different approach, shows that an average of 150 lux at the central part of the building is common, while the maximum of 400–1000 lux must be associated with specific and significant uses of light in a dramatic or baroque sense.

The oldest example emanating from European models analysed here is the Basilica of Guadalupe in Mexico City (1695–1709), built by Pedro de Arrieta. According to the results on the plan, the luminance average must have been between 100 and 250 lux. In this specific case, no difference has been found between the altar and the nave, likely because of its centralized plan. The next example, the Cadiz Cathedral (1722–1838) is much more complex. During its building process, different technical discussions emerged, including those about lighting effects. Summarizing it from previous studies (Luengo, 2019), it can be said that the final building emphasizes the transept with results of 5000 lux, while both the lateral naves and the presbytery remain at 1000 lux. It seems clear that the pattern is maintained, but the luminescence increased in the subsequent projects proposed that century. Finally, the now-lost Manila Cathedral (1750–1764) was designed to allow an average luminescence of 330–500 lux at the central nave, while lateral ones and especially the transept remained bleaker.

## Conclusions

These analyses, along with those previously published, demonstrate that there was a lighting pattern to be preserved on different continents, even when contemporary treatises and contracts rarely address this topic. The presbytery is usually dark compared with the light of the nave and the choir. Along the same line, walls are not illuminated, highlighting the central space. Finally, it is noteworthy that sunlight is avoided, in favour of a more homogenous solution. This solution is clearly linked with the liturgical functions of artworks. On the one hand, avoiding direct sunlight on the walls is required to preserve paintings, which must be kept under 250 lux. On the other hand, darkening the main altar allowed priests to use candles and mirrors to theatrically manage artificial light at every event. Finally, highlighting the upper part of the building stressed the building's divine character while simultaneously reducing the effect of heat in tropical climates. After this baroque solution, which was part of the Enlightenment, churches were clearly better illuminated, by an average range of 300–500 lux. Such levels brightened the spiritual space while at the same time made it impossible to maintain the variety of artworks previously used. Paintings, tabernacles, little chapels, and even pipe organs and choir stalls were eliminated or simplified as part of a new paradigm, an effect of this new lighting scenario.

Choosing dark spaces in the most relevant parts of the building requires the consideration of the use of candles, the analysis of which previous studies have initiated, although they focus on other chronological and geographical contexts (Moullou, Doulos and Topalis, 2015). While much research should be performed on the analysis of different historical luminary tools and their materials (e.g. spouted lamps and floating-wick lamps, fueled either by oil, beeswax, fat or tallow), it has been demonstrated that a single candle should provide less than 20 lux at 25 cm when fueled by olive oil or a little more when made with beeswax (Moullou, Doulos and Topalis, 2015). According to contemporary engravings showing the interior of churches or the institutional budgets dedicated to lighting, it seems that the number of candles could reach more than one hundred during large festivities. Considering that most of these celebrations were held during the day, their effect depended on the darkness in the presbytery. Combining the results with the possibilities of artificial light, it is clear that they allowed priests to manage light to emphasize liturgical spaces or pieces in a freer manner than could sunlight. As a consequence, this paper demonstrates that the function of light was preserved in different geographical contexts. Lack of skilled architects, challenges due to natural phenomena like earthquakes or different cultural approaches to light were not obstacles to maintain a common interpretation of sacred space. Therefore, presbyteries were kept dark to be artificially and theatrically illuminated by candles. On the contrary, naves had more sunlight. In any case, the rays of the sun were not common in preference to faint effects.

In addition to these conclusions, it is important to focus also on methodological challenges as they relate to the historiographical discussion. From the examples here, it can be said that analysis from basic manual reconstructions is a good preliminary step. From these, it can be shown how light is generally used in the church. Thereafter, it is possible to identify some instances wherein the architect seems to have paid little attention to this possibility, probably eliminating the need for further simulations as well as identifying some national characteristics, e.g. elucidating differences between French, Italian and Spanish traditions, a possibility yet little explored. Similarly, the role of decoration cannot be understood as a mere decorative function. On the contrary, furnishings might be the reason for the general lighting display, as has been noted in Rome's Gesù Church (Levy, 2004); or furnishings may underline the iconographical discourse. For this reason, paintings, tabernacles, pipe organs, among other examples, play a significant role in the analysis. Assuming this to be true, the current technical problem must be addressed. Both from photogrammetrical or laser scanning, the reconstructions incorporate these pieces as they currently exist. Whether by reducing detail or removing textural information, the interpretation of light can be carried out. It is reasonable to think that such issues of processing capacity will be resolved in the coming years, it being preferable to begin from the best digitalisations possible. In addition to all this, it is important to note that traditional analyses based on results from plans and profiles are not enough, precisely because of the relevance of these artworks. As an initial approach, it would be interesting to examine the effects of light on them, while it is also significant to control how the light is perceived by the user, and thereafter, what the results show at 1.60 meters.

From the results obtained, several questions can be addressed. Most of these churches have been subsequently modernized with artificial lighting. Due to their dimensions and daily activities, both the economic and environmental costs are significant when the solutions do not stress the original spatial conception but instead create a completely different display. For this reason, in addition to these two problems, the building as an example of the past is not highlighted but somehow modified. It is evident that the liturgical requirements have changed considerably after the Second Vatican Council, and more specifically after the *Sacrosanctum Councilium* constitution (1963). Nevertheless, the discussion about the characteristics of the religious space must be opened from a more sustainable perspective. Finally, there is an increasing interest on empirical studies on the topic. Religious space requires the movement of the user to be understood, and such activity produces changes in perception. Future approaches might connect the results recently published by psychologists on the matter (Skarlatou, 2011), and couple them with a historically logical use of the space, to begin analysing these spaces more interdisciplinary.

## Figures

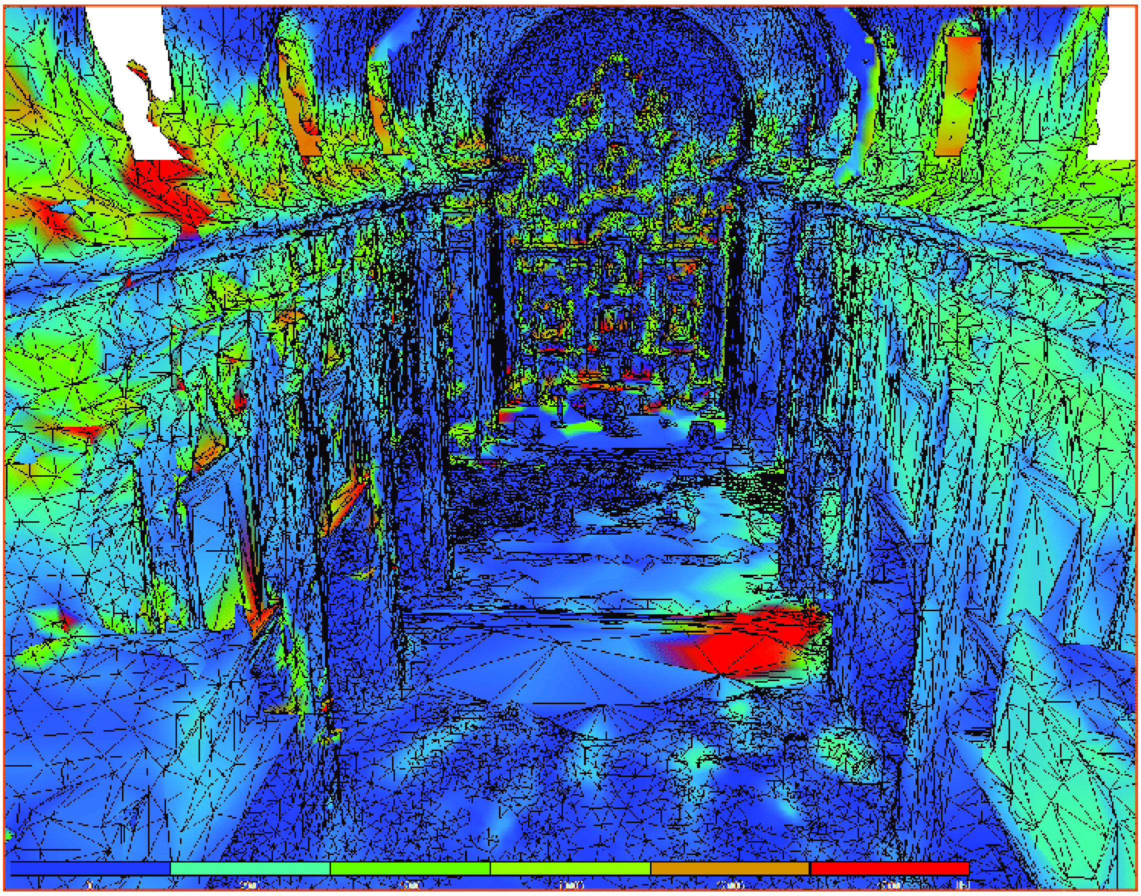

*Fig. 1. Digital analysis of light incidence in San Jacinto Church. Seville, Spain. (© P. Luengo)*

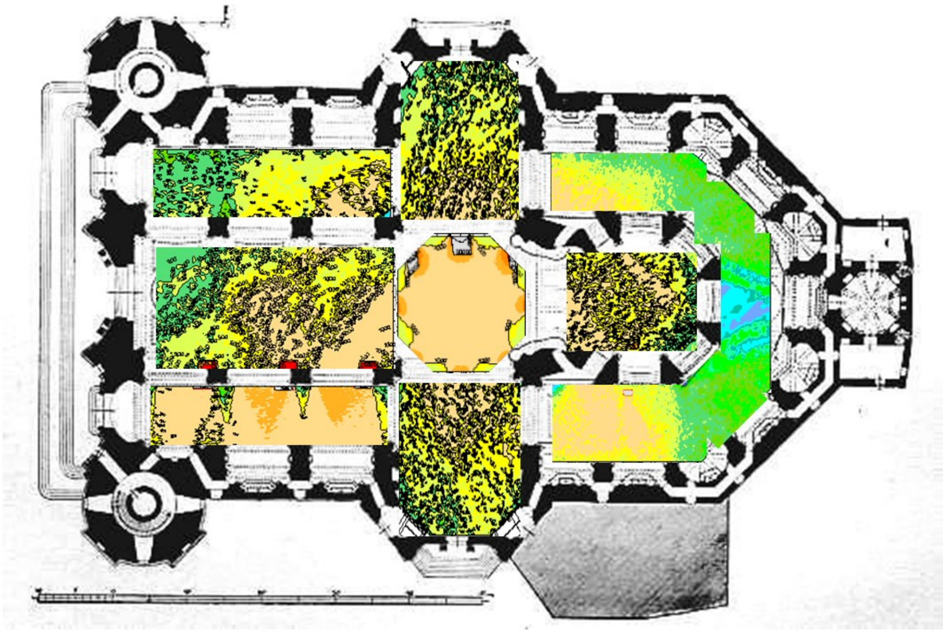

*Fig. 2. Digital analysis of light incidence in Cadiz Cathedral. Cadiz, Spain. (© P. Luengo)*

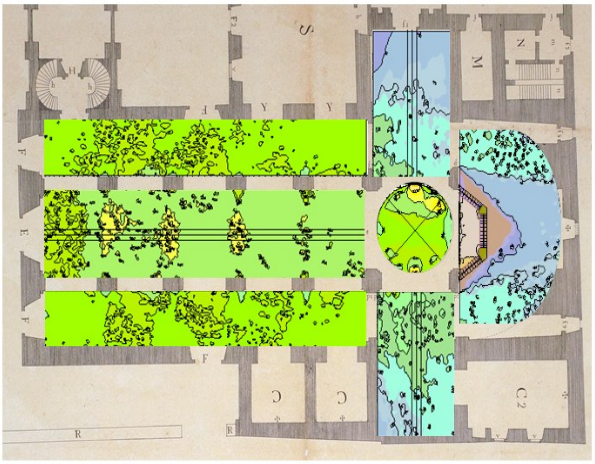

*Fig. 3. Digital analysis of light incidence in the eighteenth-century Manila Cathedral. Manila, Philippines. (© P. Luengo)*

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# Addressing Lighting Issues in 3D Model Colorization

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**Abstract:** The digitization of existing sites is a really efficient way to obtain a very large amount of data (shape, geometry, appearance…). Photogrammetry and/or 3D scanner devices coupled to a camera offers a good solution to obtain a digital reconstruction of an archaeological site or an object of interest in order to present it to users via different media (web presentation, virtual reality, immersive system, ...). But both in photogrammetry and in lasergrammetry, in order to get a complete model of a wide site and to minimize the so-called geometric shadows, it is necessary to perform a large number of acquisitions from a variety of viewpoints.

In natural uncontrolled climatic and light conditions, such as archaeological and architectural outdoor sites, the magnitude of the acquisition time induces risks of changes in the lighting conditions (like effects due the sun positions or the weather changes). The variations of the brightness, the lightning, and the acquisition parameters can induce wide differences in the visual appearance of a given scene. Without additional processing, obtaining a visually correct rendering of the appearance for digital models remains an open issue in this field of multi view rendering.

The paper promotes a method, compatible with fieldworks, that produces visual representations of sites with consistent and homogenous colorization. Image stitching and weighting methods are adapted to perform per pixel colorizations, considering all possible colors sources (photographs) in order to color each point of the model. Each contribution is weighted using a quality measure based both on geometric configuration and pictures content (e.g. avoiding exposure problems).

In addition, a lighting prototype for 3D scanners is proposed to fill the gaps in current systems for acquisition in no light conditions.

***Keywords:*** *3D laser scanner—color acquisition—multi view colorization—lighting problems*

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## Introduction

### Visual Appearance of a Material

Visual appearance is probably one of the most critical parameters affecting an observer's perception, as well as their judgment or initial understanding of what is being presented to them. Appearance is therefore a subjective property inaccessible to direct measurement for Leloup et al. (2012). To quantify it, it is necessary to determine the physical parameters or optical properties that can be measured (Schenkel, 2017).

It is possible to characterize the optical properties of materials according to four paradigms related to behavior toward light: *color* and *texture* (which depend on the spectral and spatial distribution of the reflected light), as well as the *brightness* and *translucency* (which depend on the geometric or angular distribution of the reflected/refracted light). In addition, these different attributes are not independent, influencing each other, which complicate the appearance measurement of a material.

- Color is the interpretation of a visual system stimulation. By nature, the perceived color is subjective and can therefore depend on different factors like the background, its distance from the observer, the ambient color, the lighting conditions, the environment. Objectively, the color measurement is based on the spectral reflection factor, which can be obtained directly using a spectroradiometer, and indirectly with a camera.
- Texture reflects the effects of local variation and non-uniformity of the object surface, in connection with the various external factors, the lighting direction, and the observation distance. In terms of visual response, this characteristic results in a perception of roughness, softness, waviness … (Eugène, 2008).
- Brightness refers to the shininess of a surface in opposition to a mat object, or to its ability to change its appearance following the observation or illumination angle. By definition, it is a measure, at the level of visual perception, of the property of a surface to reflect light in preferential directions. It is commonly characterized using two tools: the glossmeter and the gonio-spectrophotometer.
- Translucency reflects the internal optical behavior of the materials. In fact, the color appearance will vary depending on the light scattered (its color), reflected (its brightness) and transmitted by the object. It depends essentially on the way in which the photons will scatter and varies from transparent, passage of light without dispersion but with a possible absorption depending on its wavelength, to completely opaque, passing through the phenomenon of transluminescence (i.e. subsurface scattering).

Taking into account the different light sources in the materials rendering is important for obtaining photorealistic results. The ideal solution for this is then to fully characterize the different distribution functions: Bidirectional Reflectance Distribution Function (BRDF), Bidirectional Transmittance Distribution Function (BTDF), and Bidirectional Scattering-Surface Reflectance Distribution Function (BSSRDF). The principle of their measurements consists in illuminating a surface and in measuring the luminance in the direction of the sensor, for a sufficient number of pairs of directions to adequately sample (in number and in distribution) the parameter space (Schenkel, 2017).

In practice, the acquisition of BRDF is therefore very poorly suited to real sites under natural and variable environmental conditions. Indeed, ensuring the sampling and the coverage of the acquisitions requires the use of specific equipment, in particular for controlling the sensor. In addition, a real scene is not limited to a constant point light source, but also includes indirect sources (like reflection on surfaces) and variabilities depending on climatic conditions and sun movements. It is thus not obvious to acquire a sufficient amount of input data to reduce ambiguities relating to all of these variables, while keeping this quantity within an achievable limit. Finally, the proposed approximations require specific data, methodology, or equipment when acquiring the data. It is therefore almost impossible to completely characterize a BRDF at each point of any scene under variable natural conditions. The problem is relatively similar for the data acquisition necessary for the estimation of other functions (BTDF, BSSRDF) useful for photorealistic rendering.

Alternatively, methods have been proposed for working in outdoor scenes without heavy installation. However, this imposes many restrictions. Bernardini and Rushmeier (2002) use different approximations of BRDF based on a reduced number of measurements and on the adjustment of a lighting model. Love (1997) bases his solutions on a model of the sky and the sun, for acquisitions carried out under a clear sky, while Yu and Malik (1998) extend this idea by using photographs of the sky and the surroundings. Gibson et al. (2001) simulate a certain number of virtual light sources positioned around the scene to deduce the properties of the surfaces. Debevec et al. (2004) introduce a measuring device to precisely determine the light source, thus improving the results. Sato et al. (2003) use the presence of shadows in a scene to determine the lighting and BRDF of flat surfaces. Nielsen and Brodersen (2004) focus on estimating the properties of polished materials under complex but constant uncontrolled lighting, without a priori consideration of its position. Lalonde et al. (2012) propose a method for estimating the complete illumination of the sky using the information available in a single exterior image (the appearance of the sky, the presence of shadows on the ground or even the shading of vertical surfaces). This solution remains limited for photographs of details due to lack of information.

One solution is to use photographic images. In this case, the apparent texture is plated on the digital object by applying an inverse projection. The appearance capture for the same surface is then limited to taking a set of photographs, partially taking into account the luminous properties. In addition to geometric considerations, on-site scanning must take into account factors influencing photographs.

## Factors Influencing the Photographic Result

Some principal factors influence the photographic result.

### Influence of Natural Lighting

For most surveys, the measurements are spread over time, which makes it impossible to acquire all the pictures under the same conditions due to changes in natural luminosity (like sun and cloud movements, variability in light intensity). In addition, direct sunlight is responsible for most observable critical situations (like shadows, excessive illumination, reflections on surfaces that cannot be fully characterized). Ideal conditions then consist rather in a diffuse light, which conveys the color information (without taking up the information on the state of the surface) and which can be obtained with a uniform sky. However, in practice, the variations in intensity, hue, direction, of the light from a partially or completely diffused sky are infinite. In practice, the same problem appears on architectural acquisition. Fig. 1 gives the colorization of a model part based on five different color sources, acquired independently from different points of view, without taking into account light changes.

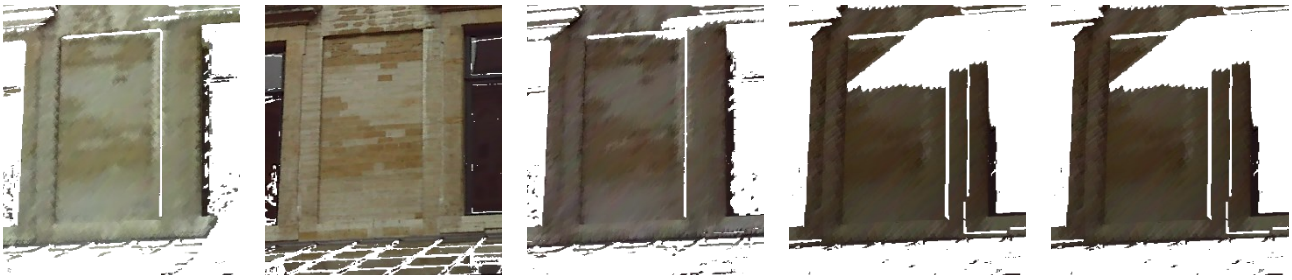


*Fig. 1. Influence of natural lighting on photographic results. Colorization of a model part with five different color sources (© Arnaud Schenkel)*

### Influence of Exposure

Defining the appropriate exposure is a fundamental problem in obtaining a photograph. The correct exposure however remains a subjective opinion; it depends on the desired effect. Digital cameras have a limited dynamic range. As a result, when part of the scene has values below or beyond this range, it cannot be rendered correctly and the portion of the resulting image will be uniformly black (underexposed) or white (overexposed), without rendering details.

In most cases the user must therefore favors either shadows or highlights. An alternative solution is High Dynamic Range (HDR) photography, which involves acquiring the full dynamic range by acquiring a series of photographs with different exposures and combining them into a well-exposed image. Mertens et al. (2009) identify several methods to merge the different contributions. However, the HDR acquisition is time-consuming and will not solve all the problems.

Complementary to the lighting, the appearance of a site is also influenced by the shadings. Shadows occur when light from a source is partially or completely blocked by an object and tends to change the shape and perceived color of objects. This is a special case of the problems of underexposure. Several image enhancement techniques, such as gamma correction, histogram equalization, evenness of brightness, or change of contrast can help solve the problem, and with less loss of detail than for overexposures.

### Influence of Additional Lightings

In a no light or in a low light environment, the difficulty is to expose the sensor sufficiently to light to collect the information from the scene. In general case, uniform ambient lightning conditions are ideal to capture the visual aspect of object surfaces, avoiding exposure and shadow problems. The use of artificial lighting sources makes it theoretically possible to circumvent the problem of adjusting camera parameters (exposure, aperture, ISO). The addition of artificial light in a scene allows for shorter exposure times, smaller apertures, and lower sensitivities, while capturing enough light to produce clear, noiseless images. The use of lighting, however, has a significant impact on the characteristics of the scene. It disproportionately brightens the objects in the scene, especially as they are close to the camera, and fades quickly. Despite these disadvantages, it remains an effective solution in low light conditions.

With photogrammetry, data acquisition can be easily coupled with a flash light or a portable diffuser. In the case of a mobile system, the lighting of the same part of the geometry will therefore not be uniform across all of the pictures due to the viewpoints configurations. With 3D scanning, there is no problem with geometric acquisition. For color, only a small number of devices use an external camera compatible with flashlight, but most of them integrate the sensor directly inside the device, making them hardly compatible.

In such conditions, it is often impossible to install standard suitable lighting devices in a large and complex survey, without creating new obstacles and thus new artifacts: geometrical related to occultations or colorimetrical related to shadows.

### Model Colorization Problem

The first problem to colorize a 3D model is to detect the correspondences between pixels and 3D points for all the geometric samples. Knowing all the intrinsic and extrinsic parameters of the camera, we can determine when a point is mapped inside an image, as well as the pixel-3D point correspondence. In addition, there are different approaches for recalculating the reverse projection necessary for these calculations for an uncalibrated photo in 3D space. In this manner, it is possible to assign a pixel color to each sample of the geometric model. The real problem arises when there are several sources that can provide this color information.

An intuitive approach is to choose the most appropriate source for each part of the model. Schenkel and Debeir (2015) identify several existing methods, such as multi-criteria selection from the best source, texture correction, blending approach, weighting of the different contributions… Without additional processing, when acquisition conditions vary over time, mixing such colored point clouds into one pattern usually produces an unpleasant rendering with a poor appearance, including apparent color discontinuities. Algorithms that require specific data or hardware were discarded. We also limit the methods to those suitable for point cloud on full-scale scene models and a reasonable computation time for real time application. We consider as the best existing candidate the class of weighing methods and we adapt then in order to take into account several important features impacting the colorization quality of the produced model.

Theoretically, the problem is only related to the acquisition of the object appearance, not to the determination of its geometry. Thus, it is general for the acquisition of colorized 3D models, and therefore present in both photogrammetry and 3D scanning processing, even if, in photogrammetry, the pictures content could influence the calculation and the quality of the 3D model.

## Proposed Approaches to Improve 3D Model Colorization

The main goal is to obtain a rendering, with a coherent colorization, of architectural site models, which can be geometrically very complex and have significant volumes. The proposed solution consists of two essential elements:

- The improvements of the shootings in the field by improving the lighting condition of indoor sites in most situations (low or no lighting) by using a specific system producing omni-directional ambient lighting, without adding any geometric or colorimetric artefacts to be treated;
- The digital color processing for each geometry element of the model, considering all pictures acquired in the field, in order to guarantee as much as possible the uniformity of the model colorization by eliminating all the artifacts present.

### Acquisition Lighting Improvement

For general lighting conditions, a conceptual prototype was developed considering different criteria:

- The lightning equipment should not be seen by the scanner, avoiding post-processing to eliminate these aberrant measurements;
- It should produce a diffuse light to avoid all lighting artifacts, and specifically over-exposures and hard shadows; and
- The produced lighting should cover the whole field of view of the scanner, both the 360° horizontal coverage and the device zenith.

The prototype was therefore designed to be positioned entirely inside the scanner tripod. It includes a series of bulbs coupled to diffusers positioned, either parallel to the ground to avoid overexposing it while uniformly illuminating the whole room, or in the zenith direction to diffuse the light all around the scanner itself. Fig. 2 shows our prototype, placed in a cellar where no natural light illuminates the surfaces, and some pictures of the walls and the roof lit with it.

*a* *b*

*Fig. 2 a) Lighting equipment prototype, placed in a cellar where no natural light illuminates the surfaces, and b) some pictures of the surrounding elements lit with it (walls and roof) (© PANORAMA).*

It is however impossible to have a lighting independent of the distance; the light intensity will always decrease. It is therefore necessary to take this effect into account when coloring.

### Model Color Processing

The proposed method consists in a colorization by vertex taking into account all the available sources of colors. Each contribution is then weighted according to a quality measure. The local quality depends on characteristics directly related to the pictures content and on characteristics related to the picture in relation to geometry.

A series of quality factors are defined to weight each contribution. Inspired by Callieri et al. (2008), Schenkel and Debeir (2015) suggest to use a geometric mean of these normalized measures to combine these scores. Thus, for each image, an evaluation of the quality of each pixel is obtained from the extraction of characteristics directly related to the content of the picture considered or related to the latter by considering its environment and the derivation of these characteristics to obtain a series of quality factors. The evaluation of a quality factor for a complete image composes a weighting mask.

Firstly, in the proposed process, the detection of problems related to the images content are limited to the shadow detections and the overexposures detections. The need to solve both problems is related to changes in brightness, which can induce unpleasant discontinuous stains by creating false edges. As illustrated in Fig. 3, a quality mask can be defined based on these detections: for an image, we define shadows and overexposed elements and determine the borders of these elements. The quality then depends on the distance of a pixel from these borders. More a pixel is far from an edge, better is the quality. Finally, the three kinds of areas (well-lighted, shadow, and overexposed) were weighted differently. A combination of these two elements makes it possible to obtain the mask of quality that we will consider.

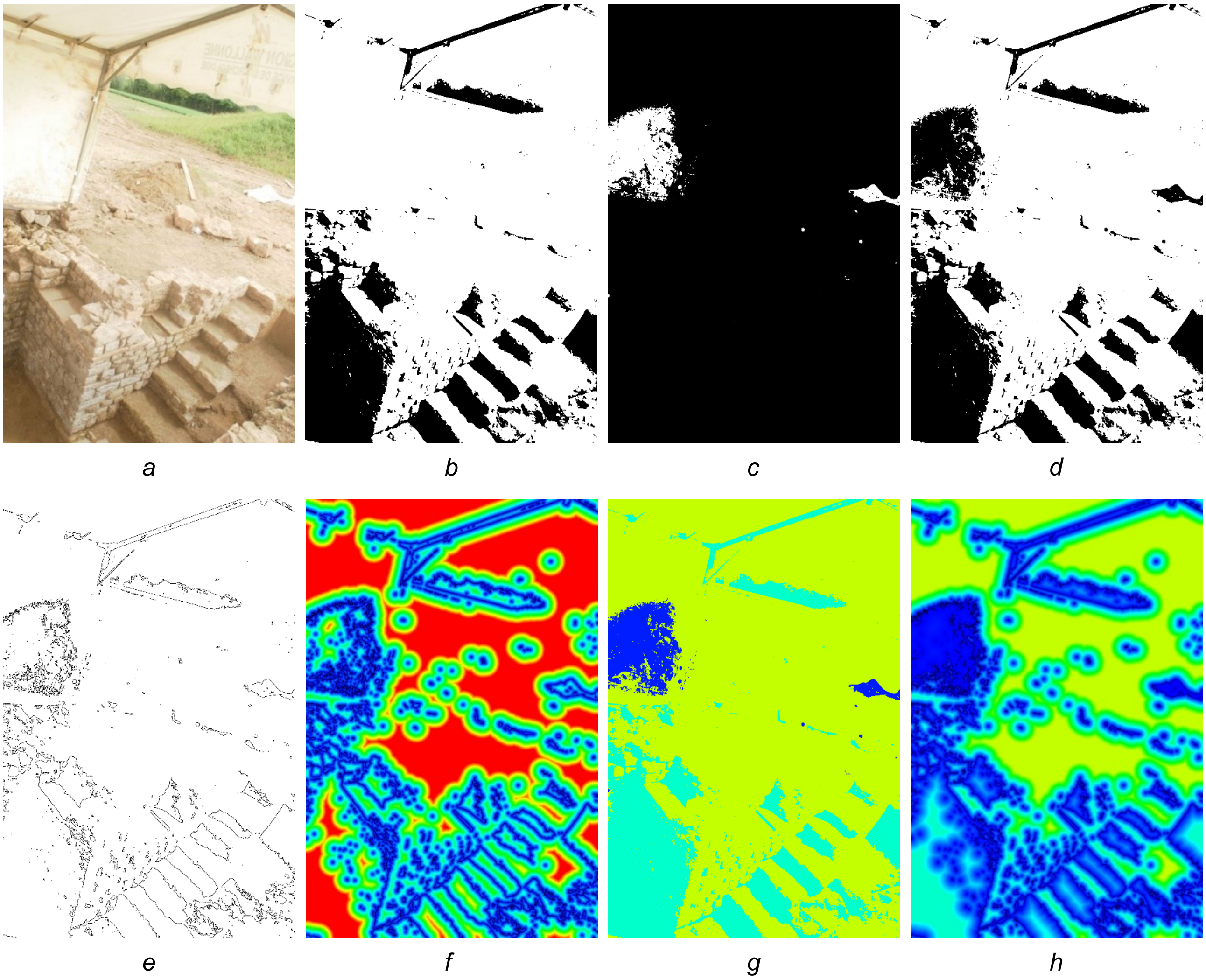
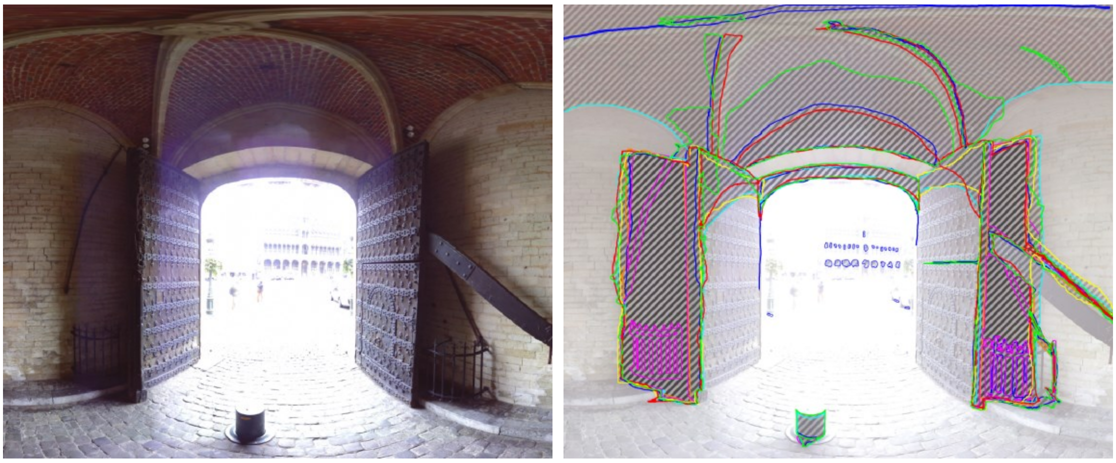



*Fig. 3. Exposure quality mask, for an image: a) image considered; b) shadows detection; c) overexposure detection; d) combination of the segmented elements; e) borders extraction; f) distance map; g) weighting of the different zones types; h) resulting mask. (© Arnaud Schenkel)*

For the shadow detection, an approach based on the distribution of intensities was promoted. More particularly, the detection is based on the value of the Pearson's moment coefficient of skewness, which measures its asymmetry, which can be associated with the histogram shape of an underexposed image, or showing shadows. Thus, in addition, the elaborated method also tends to detect clean shadows or dimly lit areas that cannot be unilaterally categorized as shadows. The difficulty of this detection is linked to the human perception of the problem: it is not easy to clearly limit the shadow areas of a complex scene with multiple lights. Humans will generally rely on the context of what they see (especially for the shaded shadow limits) to make their judgment and not only on the local colors present. Fig. 4 illustrates the ambiguity of the problem; different researchers have manually segmented the main shadows. The proposed solution gives good results (according to a visual evaluation) for fixed parameters.



a b

*Fig. 4. Manual segmentation of shadows by different researchers: a) reference image; b) segmentation. Each segmentation is associated with a different color. The hatched areas represent the parts determined at least once as a shadow; its intensity varies according to the number of similar decisions. (© Arnaud Schenkel)*

About the overexposures, the method combines the detection of shadows on a negative image and an adaptation of the thresholding proposed by Yoon et al. (2014) and based on human perception. Fig. 5 gives the results of these detections for an image.

a b c

*Fig. 5. Proposed shadow and overexposure detections: a) initial image; b) shadow detection discrimination map; c) overexposures discrimination map (© Arnaud Schenkel).*

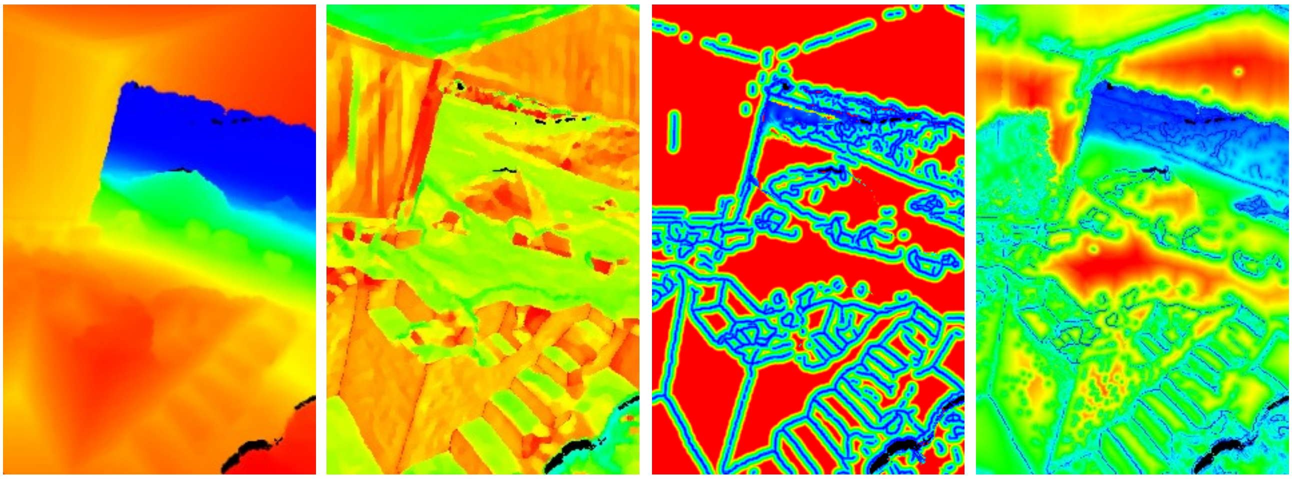
The second step of the proposed approach consists in extracting elements of the acquired geometry relative to the image considered. Two data are essential in this specific colorization process: the depth map and the normal map. These two sets of data are firstly necessary to determine which part of the dataset is visible from the camera, and secondly derived to extract different masks of quality.

In general, sources close to a surface are more representative and better reflect the details than distant viewpoints. The distance between a color source and the geometry reflects both the amount of light reaching the object, the ratio between the pixel number and the surface area, or the illumination due to a light source (e.g. additional lights). Therefore, the quality of a color source is considered especially as a function of the distance.

Then the orientation of the photos in relation to the model was considered. The quality of a color source is greater when the image plane is parallel to the geometry, and varies according to the incidence of the viewing angle of the surface. The angle between the surface normal and the optical axis thus reflects a local quality of the pictures. Orientation quality factor discredits bad oriented color elements.

Within a 3D model, there are essentially three geometrical characteristics depending on the view where the visibility of a surface can change: the silhouettes, the edges of the surfaces, and the crease. The elements related to these points in the pictures present certain characters of uncertainty, both in terms of position in space and in terms of color consistency (these pixels in the image can potentially represent several non-contiguous regions). Taking into account such discontinuities in geometry allows better rendering of a model; silhouette quality factor discredits blurred and anti-aliased pixels.

Fig. 6 gives an illustration of the considered quality masks, related to one picture.



a b c d

*Fig. 6. Quality masks, calculated for the image used in Fig. 3: a) distance; b) orientation; c) silhouette; d) combination of all quality factors (© Arnaud Schenkel).*

## Results

To obtain a consistent colorization of a model, it is necessary to have a redundancy of colorimetric information. A low level of overlap between images and between scans will induce increased risks of having visible transitions, non-homogeneity in colorization and differences in colors due to changes in brightness or hue between photographic acquisitions. The proposed method makes it possible to remove most of the visual artifacts, when a 10 % overlap is present in each set of images.

The result obtained thus gives a smoothing of the transitions and a uniform colorization, both at the level of a scan and at the level of the complete object.

The proposed method was evaluated on acquisitions made using two scanners, a Riegl LMS-Z360i coupled to a camera equipped with a flash and a scanner FARO 3D S350 with an integrated camera. The method provided quality colorizations for all the acquisitions, as well for small surveys (e.g. Merbes-le-Château, including 4 scans and 32 photos) as complex surveys (e.g. City Hall of Brussels, including 97 scans and 5841 photos).

Fig. 7 gives a comparison of the results obtained for the acquisition of the El Castillo Cave (Spain), comprising 177 scans and 1770 photographs using flash light. The cave is relatively dimly lit, requiring additional lighting. The site has a complex geometry, composed by large pieces and long corridors. The photographs in this dataset are particularly impacted by the use of additional light, presenting areas that are largely underexposed when they are distant from the camera.

*a* *b*

*Fig. 7. Results on El Castillo Cave dataset based on a point cloud rendering: a) scanner software colorization and b) our proposition (© Arnaud Schenkel).*

The survey of Merbes-le-Château was made outside. The acquisitions were therefore impacted by climate change, resulting in the presence of overexposed and shaded areas. Fig. 8 shows the difference in results obtained with and without detection of exposure problems. This effect is mainly seen at the stairs and at the ground.

*a* *b*

*Fig. 8. Comparison of the results based on a point cloud rendering: colorization a) without and b) with the exposure problem detection (© Arnaud Schenkel).*

Additional results are available on PANORAMA website: http://panorama.ulb.ac.be/.

## Conclusion

The promoted method allows to quickly obtain a visually pleasing rendering, by ensuring, for each geometry, the use of the same color sources in each overlapping zone during the colorization process. The developed method allows to keep the model suitable for different studies, while allowing to consider other types of corrections and improvements proposed in the literature. This method is easily integrated to the field acquisition process to rapidly observe gaps during fast site scanning, without requiring the use of brightness control techniques. The developed prototype tries to fill the hardware lack of sufficient integrated lighting in the content of indoor acquisition where no natural light is available or possible (saddlers, cellars, caves, etc.) and where the total pitch-black limit the HDR mode usage. The prototype will be enhanced with a power controller to manage the intensity following the volume to be enlighten. Portability (power battery, deployment, compactness) will also be improved.

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## Session:
## Learning from the Past

### Facing modern challenges by integrating historical and present-day data on rural and urban infrastructure

Rowin van LANEN | Menne KOSIAN | Jaap Evert ABRAHAMSE

# Learning from the Past

## Facing modern challenges by integrating historical and present-day data on rural and urban infrastructure

Chairs:
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Menne KOSIAN, Cultural Heritage Agency of the Netherlands, Netherlands
Jaap Evert ABRAHAMSE, Cultural Heritage Agency of the Netherlands, Netherlands

***Keywords:*** *Historical infrastructure—multi-scale variability—digital techniques—multidisciplinarity and data integration—visualizations and reconstructions*

The spatial layout of towns and infrastructure provides information on past human-landscape interaction. And although dynamic in nature, many of these spatial constructs have continued to exist in the present-day landscape.

River-delta areas are generally low-lying; their landscapes shaped by marine and fluvial influences. In Europe they are often divided in two main landscape types: the lower, dynamic Holocene soils and higher, more stable Pleistocene areas. Remarkably, the more densely populated areas were often located in the more dynamic Holocene parts, especially in the proximity of rivers channels. Because of their fertile substrates, easily maintainable natural boundaries and abundant transport options these landscapes have always attracted people throughout history. However, living in these dynamic landscapes required the inhabitants to adapt to ever-changing circumstances. This has resulted in very specific town layouts and the development of elaborate and intertwined rural and urban infrastructural works, in which water management was always a factor to be reckoned with.

At present, issues such as increasing weather extremes and urban, agricultural and economic interests put pressure on these landscapes, directly threatening the preservation of heritage. Besides providing useful knowledge of past solutions for future challenges, these historical spatial constructs also have a social function as was underlined in the recent Davos declaration (2018) on the importance of a European vision on *Baukultur*.

In this session, we invited researchers to come forward with inspiring examples of successful integration of historical and/or present-day data in order to analyse, visualize, reconstruct or preserve past urban or rural landscapes or infrastructural developments. This session focused on heritage projects using historical data to face modern-day challenges. The aim of this session was to identify, analyse and compare different methods and technologies and their effects throughout Europe.

# Global Virtual Cultural Heritage Environment with attention to disability inclusion

## A proposal for gamified immersive experiences of early watercraft and audience engagement

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**Abstract:** Early Watercraft (EW) all over the world marks the beginning of human migration, transportation, and shipbuilding traditions. Logboats, rafts, bark boats, and skin boats are among the oldest and most essential inventions of humankind, still used today by various indigenous cultures. Global existence suggests EW could be considered as one of the most exceptional universal cultural heritage despite being dispersed in diverse local and regional contexts around the world. Hence, more considerable attention should be given to this human achievement. In this paper, a new representation method for this dispersed and overlooked cultural heritage is proposed. For this purpose, a new paradigm scheme has been developed, connecting scattered scientific research with audience engagement focused on disability inclusion with Design for All principles. The proposal will be exemplified with two case studies from Slovenia, and Australia later tested with a digital geospatial platform, the *Early Watercraft Global Virtual Cultural Heritage Environment* (*EW GVCHE*). Since EW is a shared and inclusive heritage, it can serve as a bridge between different continents, countries and time zones, which allows the creation of a unique multi-user experience through immersive collaborative game design focused on availability, accessibility, and connectivity. Simple computer indie games inspire these low-cost and transferable solutions of short gamified Extended Reality (XR) experiences. Alongside the *EW* platform, the games will be accessed from various locations, including museums, interpretation centres, schools, and retirement villages as portable pop-up experiences. In Slovenia, a Late Mesolithic logboat from Hotiza will be used first to develop and test the proposed framework. In Australia, the framework will be further investigated in close collaboration with Indigenous Australians, the custodians of the local EW. The proposed approach is intended to be applicable to different dispersed heritage environments.

***Keywords:*** *Early Watercraft—Extended Reality—Applied Games—Disability Inclusion—Accessibility*

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## Introduction

Early watercraft (EW) can be considered as one of the earliest and most significant human inventions from technical, cultural, and environmental perspectives. The discovery that water—at the beginning rivers, lakes, and bays—can be utilized to improve human mobility represents an important historic milestone with a direct impact on human migration, navigation, trade, and infrastructure development.

"In fact, only three times in human history has man succeeded in leaving his natural habitat—dry land—and penetrating into other dimensions. On each occasion, a special 'apparatus' was required: first the boat, then the aircraft and finally the rocket." (Ellmers, 1976 [1996])

The oldest archaeological material evidence, petroglyphs of reed-bundle boats from the UNESCO World Heritage Site in Quobustan, Azerbaijan (UNESCO, 2007), shows at least 13,000 years of use. Secondary evidence of migration 44,000–50,000 years ago argues that EW may have been used by Indigenous Australians when trading between Northern Australia and Asia (Arthur and Morphy, 2019). Moreover, through another evidence of migration, anthropological theory predicts the use of EW by Homo Erectus 850,000 years ago (Bednarik, 2014). Most of the EW, such as logboats, bundle-stem boats, skin boats, bark boats, and rafts, were made from organic material non-resistant to air and UV rays (Fig. 1). Hence, these artifacts have mainly been preserved in watery environments which caused that their research has always been a logistically complicated process. The lack of archaeological data in the last two centuries resulted in having only logboats being recognized as a significant cultural heritage.

The current permanent supplement taxonomy, which is being developed by the ambassadors of a global initiative Early Watercraft—A global perspective of invention and development (EWA), identifies more than 130 types (including original names) of EW worldwide. Even though EW has been well researched in many distinct scientific disciplines such as archaeology, anthropology, ethnology, Indigenous and living tradition studies, it remains relatively dispersed and hidden in local and regional stories. With the revival or continuation of practice by some of the local communities, the tradition of the everyday use of EW (see Fig. 1) is still alive in various parts of the world (Arnold, 2014; 2015; 2017; 2019).

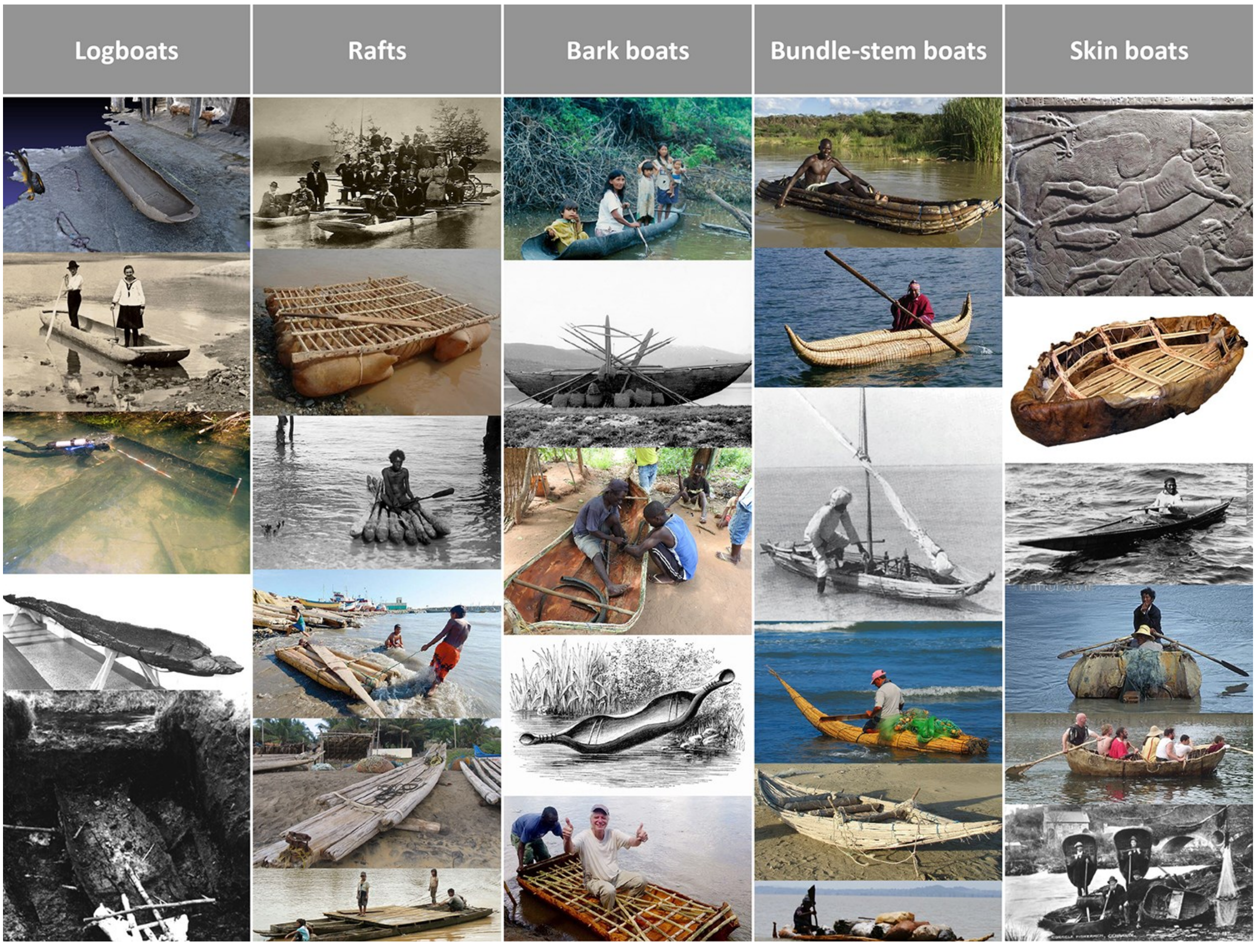


*Fig. 1. An overview of different types of EW (Internet/Wikipedia search).* ***Logboats****: © Gregor Berginc, © Miran Erič; © Stanko Ribnikar, © Aleksander Zgonc Collection; © Jože Hanc-Joc, © Skupina za podvodno arheologijo; © National Museum of Slovenia; © National Museum of Slovenia;* ***rafts****: © Ljoba Jenče Heritage House Cerknica; © Christine Tavernier; © Herbert Basedow (National Museum Australia Canbera); © Melissa Merino (La Republica); © Peter Malakoff; © Waldemar Ossowski;* ***bark boats****: © Beat Arnold, © Elton Rivas; © Mission Scientifique du Cap Horn; © Beat Arnold; © Beat Arnold, ©Mathews; © Beat Arnold;* ***bundle-steam boats****: © Ariadne Van Zanderbergen (APA Publication); © Andre Engels; © Ramin Adibi (Journal of Archaeology of Maritime Landscape Magazine); © Martin Garcia; © Ramin Adibi (Journal of Archaeology of Maritime Landscape Magazine); © Brian J. McMorrow;* ***skin boats****: © British Museum; © Anchorage Museum Association Acquisition Fund; © Samuel Herbert Coward (McCord Museum Montreal); © Direction Canada; © Simon Speed; © The Museum Collection of Cyngor.*

This proposed project addresses the issue of EW being often scattered in small, seemingly insignificant local heritage stories. A global virtual CH environmental approach developed in the last decade provides new challenges and opportunities on how to curate such dispersed heritage. Throughout recent years, a new CH paradigm and methodology to represent this extraordinary human invention through a virtual environment is being developed. Moreover, the latest development of modern underwater archaeology and sophisticated 3D digitalization tools have accelerated the interest of a wider heritage community in studying and digitally interpreting EW (Erič et al., 2013). However, a vast majority of scientific 3D digital/digitized assets and similar material stay in online heritage repositories accessible only to scholars. Such repositories have now matured to a stage where they became a rich and flexible virtual environment. Despite that, less complex and integral ways should be established to contextualize and communicate such resources for wider audiences.

An exceptional development of computer games in recent decades has enabled interactive history (Champion, 2015) in the form of applied or serious games, which are widely used in museums and schools. Moreover, the democratization of Extended Reality (XR), including Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR) and, 3D printed replicas/reconstructions, are shaping a new wave of digital heritage interpretation and audience engagement (Antlej et al., 2018a; 2018b). Immersive gamified experiences are thus becoming more suitable for heritage interpretation.

The proposed project intends to follow the well-known design approaches such as Design for All, Universal Design, and Human-Centered Design to ensure that the contents are accessible by broader audiences with different abilities. Special attention will be given to people with various impairments since this population is rapidly growing, among others due to the aging of society (Rebernik, 2019). Moreover, putting the needs of the most vulnerable heritage users, such as those with disabilities, elderly and other people with various impairments first, might also help to influence the way how technology is used for heritage representation and interpretation to enhance inclusion for all (Deffner et al., 2015). As scholars and practitioners have suggested (e.g. Hanson, 2004; Imrie, 2012; Rebernik et al., 2019), if the design is performed with the disability inclusion in mind, other users can also benefit from it. Universal Design or Design for All refer to services, products, and spaces (European Commission, 2015) and mean accessibility and inclusion for all. Human-Centered Design (HPIDSU, 2020) is a creative problem-solving philosophy focused on users, their needs and wants.

We selected in this article two case studies to discuss and develop a framework for communicating scientific data of both archaeological and anthropological/ethnological dispersed heritage in XR. First, XR experience gained in Slovenia with the interpretation of the seventh oldest known logboat worldwide from the Late Mesolithic (7,000–6,000 BC) found in the river Mura near Hotiza, will be further developed based on available scientific data and will be tested on end-users. Second, in Australia, a scientifically informed XR experience about living EW heritage will be developed and evaluated in collaboration with the local Indigenous community, the oldest living culture in the world. The combination of these two scientifically and culturally significant heritage cases has been carefully chosen to represent a broad spectrum of globally dispersed EW heritage content. As the logboat from Hotiza characterizes an archaeological artifact, Indigenous Australian EW is mostly in the domain of anthropological/ethnological research. In other words, the approach of how archaeological and living heritage is interpreted may vary. The two exceedingly different cases will assist in the development of a framework applicable across various EW objects. From a geographical perspective, regarding the local heritage audiences, the proposed cases cover two different continents on the Northern and Southern Hemispheres. This locational diversity provides challenges for accessing and experiencing "each other's" dispersed heritage content as well as opportunities to investigate how to overcome such issues.

To address the identified challenges and opportunities, this article discusses a proposal to develop an engaging Global Virtual Cultural Heritage Environment (GVCHE) using EW as the study case with special attention to disability inclusion. Our research investigates the following questions:

- How can dispersed heritage of EW be connected globally not only from a scientific but also from a community engagement perspective?

- How can scientific 3D digital/digitized assets of EW be contextualized as a meaningful content to assist wider audiences to better engage with EW?
- How can gamified Extended Reality (XR) be used for creating engaging experiences for all, including people with diverse impairments?

## A global network of Early Watercraft Heritage

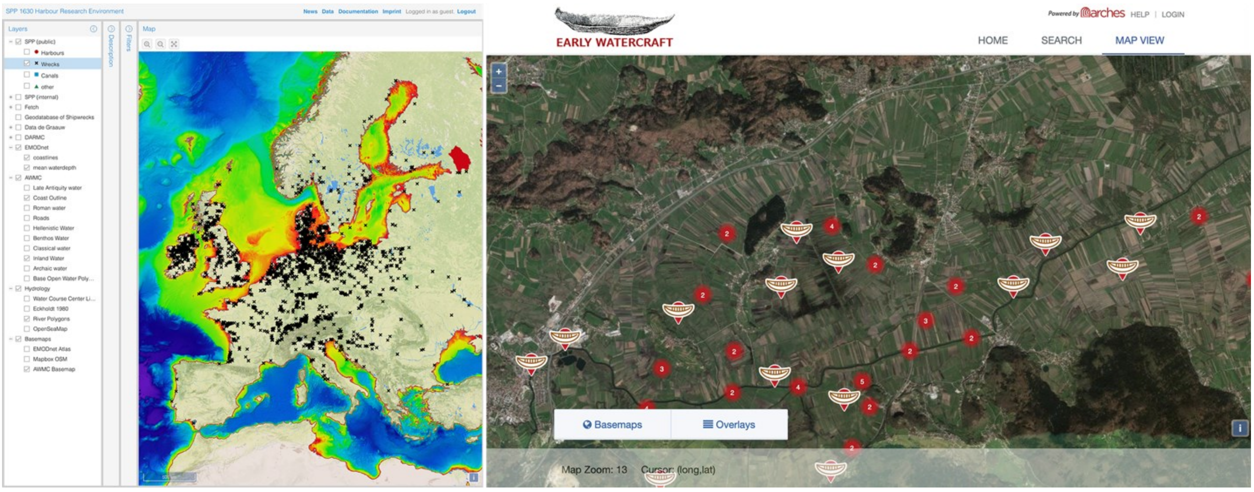


*Fig. 2. Harbour Research Environment (HARE) of the SPP 1630 Harbours Program (left). Early Watercraft, a web repository showing logboats from Ljubljansko Barje. The first testing database was programmed on Arches V3.0 by © Bojan Kastelic, Computer Vision Laboratory, Faculty of Computer and Information Science, University of Ljubljana (right).*

The proposal of the GVCHE presented in this article is based on the EWA Global initiative, which was inaugurated in 2015, in Vrhnika, a city in Slovenia, near one of the UNESCO World Heritage Sites – Prehistoric Pile Dwellings around the Alps (UNESCO, 2011; Erič, 2014). The EWA Global initiative aims to connect researchers interested in EW into a global network and to provide an open forum to geo-locate and exchange data, as well as to discuss strategies to recognize this type of dispersed heritage as a significant human achievement.

When this article was being written (May 2020), 109 individuals and 32 institutional Ambassadors from 53 countries from six continents were involved in the EWA network. The birth of the initiative coincided with Early Watercraft, a web-based geospatial information system published by the University of Ljubljana and the Institute for the Protection of Cultural Heritage of Slovenia.1 The platform runs on Arches (v3.0), an open-source data management system for heritage developed by the Getty Conservation Institute and World Monuments Fund.2 Currently, the EW platform (v1.0) includes detailed information on almost all known (92) logboats from Slovenia (Fig. 2, right). The platform is aiming to expand into a GVCHE to include the European database with almost 3,500 logboats (Fig. 2, left) recorded from the early 19$^{th}$ Century until today (Arnold 1995, 1996; Kröger 2018).

Each artifact in the EW includes not only its location, dating, condition, and related publications, but contains also visual materials such as data images and 3D models reconstructed either from

[1] www.earlywatercraft.org
[2] www.archesproject.org

archaeological drawings or from 3D digitalization. The EW platform is in principle targeting researchers and is therefore too elaborate for a wider audience with different abilities for learning and comprehension.

## Disability inclusion in heritage

Heritage gives us a sense of belonging and identity. It touches the deepest parts of our human experience, which reaches beyond just fulfilling one's everyday routine. Hence, it is of paramount importance to make heritage accessible and inclusive to all. Accessibility and inclusion are, however, relative concepts. Accessibility can be perceived in broad terms of access and availability of spaces, services, products and information. In narrow terms, it can be perceived as a feature that responds to the needs of persons with disabilities. In more specific terms, one could think of physical accessibility (e.g. access to spaces), information-communication accessibility (e.g. access to media, books, lectures, websites, instructions, and notifications) or intellectual accessibility (e.g. making contents easy-to-read and spaces easy to navigate). Inclusion may be understood in broad terms (e.g. social, economic, and spatial inclusion) or narrow terms (e.g. disability inclusion, gender-based, age-based, and ethnicity-based) (Rebernik et al., 2014).

Herein we direct our focus onto exploring ways as of how to make cultural heritage accessible and inclusive to those people with diverse impairments and disabilities (Fig. 3, 4), for them to be able to enjoy it on an equal basis with others (UN General Assembly, 2007). Immersive digital technologies and tools nowadays offer countless opportunities to achieve this goal. Not only to reach beyond physical limitations of space, but also to create opportunities for making heritage accessible in ways concerning representation format and content even for sensory and intellectually impaired.

Virtual presence and distance accessibility, satellite connectivity, multimodality, and many more of the technological advances enable people with impairments to experience the world heritage beyond the traditional logic of materiality. A person in a wheelchair will be able to access physically inaccessible heritage in immersive ways from the comfort of their home. People with visual or hearing-impairment will get immersed through multisensory experience combining audio, visual, and haptic forms of content interpretation. Individuals with an intellectual impairment will learn about heritage through easy-to-understand contents, gamification, and visualizations (Pavlin et al., 2015). As we see, technology can help create a new inclusive paradigm where no one is left behind. However, there is still a long way to go, as the design is done by people for the people and thus requires strong partnerships with user-centered and audience engagement methodologies.

In the two presented case studies, we undertake an ongoing concern of the needs of people with physical, sensory and intellectual impairments, aiming at providing them with a unique global heritage experience in an accessible and engaging way. By partnering with people with disabilities and diverse experts on disability inclusion, digital accessibility, and inclusive education, and following guidelines such as Web Content Accessibility Guidelines (WCAG, 2018) standard, this research attempts to explore how to bridge the barriers that current heritage practices still predominantly impose on people with disabilities (see for example Rebernik, 2014; Riganti, 2017; Hayhoe, 2019).


*Fig. 3. People with disabilities and an example of their interaction with heritage in a museum (© Nina Oman 2013) (Rebernik, 2014)*


*Fig. 4. People with disabilities and an example of their interaction with heritage in a museum (© Nataša Rebernik)*

## Gamified XR EXPERIENCES as a way to engage audiences with a GVCHE

Games in their basic form are a challenge or a scenario. They present the player with a challenge and "force" them to learn new skills and improve their abilities to solve the challenge. An immersive, interactive, multimedia representation through which compelling problems are presented, invites the player to engage and make world-changing decisions (Gee, 2007).

Research studies show that an engaging, interactive experience fosters learning through self-sustaining cooperation, avoiding a ‘Vegas Effect’ (Dubbels, 2019) – learning that happens in games, stays in games, instead of being transferred to real life. Games enable learning through measured feedback by interacting with a game environment (Dubbels, 2019). Well-designed video games are intrinsically motivating (Malone, 1981; Dicheva et al., 2015). With immediate feedback, games implement a variety of optimal teaching and learning strategies (Gee, 2007), as well as encourage exploration and identification with virtual avatars in the pursuit of knowledge (Turkle, 1984; McCall, 2011). The repetitive nature of games allows players to experiment with different behaviors, modes of problem-solving, and interaction styles with complete safety (McDaniel and Vick, 2010). Users memorize information subconsciously because it is meaningful to the storyline, a subtle feature of the game, or a method of winning the game, resulting in an engaging experience, where learning emerges as a side effect (Malegiannaki and Daradoumis, 2017; Breuer and Bente, 2010). In the context of heritage, applied games, therefore, represent a valuable medium for learning through play.

In archaeological heritage, computer games have been used for a few decades. *Rome Reborn* initiative, launched in the mid-1990 by the UCLA Cultural Virtual Reality Laboratory, for example, deals with the reconstruction of Rome in the period around 320 AD through a series of apps and videos (Frischer et al., 2006). The latest version includes VR technology and is available for free at [www.romereborn.org](www.romereborn.org). A series of archeology-themed games *Excavate!* by Dig-it! Games enable players to learn about ancient civilizations through archeological research as one of the key game mechanics. The theme of Ancient Egypt is available for free at [www.dig-itgames.com/excavate/](www.dig-itgames.com/excavate/). Another more recent example of an interactive VR experience is *Nefertari: Journey to Eternity,* also available at no cost on one of the biggest gaming platforms in the world—*Steam*. It allows a player to visit and explore Nefertari’s tomb. Even in mainstream games such as *Assassin’s Creed: Origins* and *Assassin’s Creed: Odyssey* archeological and historical research took the lead in an educational game mode known as *Discovery tour*. This mode is similarly available on *Steam* separately from the main game. Additional recent examples are discussed by Lobinger and Hemker (2018), Bercigli (2018), and Aschauer et al. (2018).

For creating an engaging gamified heritage experience, it is vital to understand the concepts and elements behind entertaining commercial games. Gamification has already tried to achieve learning through entertainment. The term is usually defined as the use of selected game mechanics (points, badges, levels, leader boards, ranks, and rewards) in a non-game context to engage the users in an attempt to superimpose the stimulating motivational aspects of the game world onto the real world (Dicheva et al., 2015; Sharritt, 2010). However, positive feedback is merely a tool that provides structure and measures progress within a system (Bogost, 2013).

A gamified heritage experience should not only borrow a few selected elements of a game, but it has to be inclusive, enjoyable and tailored to the needs of target audiences. Hence, it is essential to examine the concept of personalized gameful design as well as the psychological and motivational factors present in most commercial games. Gameful design, first and foremost, considers the user experience before adding any game elements. The approach recommends to intentionally design for gamefulness using game design thinking even when developing experiences in non-game environments. Instead of attaching game mechanics to various tasks in the experience, the tasks themselves are designed similar to games, without having to rely on external reward systems (Dicheva et al., 2015). Personalized gameful design (Tondello, 2019), known as adaptive gamification or tailored gamification, takes that concept one step further. This approach improves the user experience by allowing each user to have a different experience with the system, based on their individual preferences and abilities.

An immersive gamified experience should also provide value in function, emotion, and through playful interaction, encourage learning and social interaction (Dubbels, 2017). The psychological and motivational factors of an engaging and fun game experience can be broken down into four elements present in the principles of a few rather well-known motivational theories and models. Maslow's hierarchy of needs defines intrinsic motivators, such as autonomy, mastery, and purpose. On the other hand, self-determination theory asserts that people have innate psychological needs of competence, relatedness, and autonomy. The four elements are, therefore, the elements of *challenge*, *mastery*, *autonomy,* and one not yet mentioned, but in our case of the dispersed heritage of EW very critical—*socialization*. The easiest way to understand how the first three correlate to the concept of fun is through the flow theory, a well-known concept about way games work. This theory states that activities which are in the balance between difficulty and skill, create a state of flow that is motivational. Simply put, if the challenge is too difficult, the player can experience anxiety and frustration. On the other hand, if it's too easy, it becomes boring. The experience of flow is often described as a spontaneous joy while performing a task, an optimal state of being in which one experiences intense focus or concentration, merging of action and awareness, as well as a high sense of agency (Dicheva et al., 2015).

When building a gamified heritage experience, a number of key game elements are to be considered. One of the essential components is accumulative grading. This enables the player to be rewarded with "experience points" or "going to higher levels" after they complete a task. Visible status and progress, coupled with challenge-based learning tasks and clearly set goals, let the player and their co-players know exactly where they stand. Each goal is a learnable challenge, and with the increasing complexity of a game, retaining the flow and the range of difficulty options is not easy to design, especially when considering users with diverse intellectual and physical disabilities. The player choice component provides a sense of autonomy. A player can choose to work on their challenge at their own pace and level of proficiency. Last but not least, the freedom to fail is another element, where failure comes with no serious consequences attached, allows the player to redo the challenges as often as they want (Deterding, 2013; Tondello, 2019).

MMOs (Massively Multiplayer Online games) may potentially be a suitable type of game for a dispersed but mutual heritage such as EW. MMOs enable an inclusive social activity accessed on-location in the form of a co-located (Hochleitner et al., 2013) and co-operative play, available from home. A major advantage in creating an MMO is a relatively well-established EW community. However, building a new "gaming" community can pose a challenge. Communication being the most important component, the experience must include in-game communication (through audio, text, or live, if on location) and off-game communication through forums. Game mechanics based on co-operative gameplay typical for MMOs can create sociability when played with a friend, family member, or someone else from another part of the world. Furthermore, the game also enables a larger amount of resources, easier challenges, additional rewards, unlocked achievements, extra experience points, and similar. A system that enables and encourages social interaction, without forcing it, is crucial for the positive game experience, even in a mainstream MMO.

Considering that our goal is to create an inclusive experience intended for a particular audience, knowledge of their direct experience is also of utmost importance. There are several blogs, review sites and hubs where disabled players share their experiences with gaming in general (http://www.abilitypowered.com/, http://www.brandoncole.net/, and https://geekygimp.com/about/ among others) and which also provide helpful insight when designing a gaming experience tailored to their needs and desires.

An extensive reference list breaking down different aspects on what inclusive, accessible game design should consider and implement into a disability-friendly gaming experience already exists and is available at http://gameaccessibilityguidelines.com/full-list/, which may assist our task, though no less demanding.

## A PROPOSED SCHEME of a GVCHE

The introduced concept of a GVCHE embodies a global digital geospatial platform connecting scientific heritage data from various disciplines with audience engagement content. In order to validate the proposed model, a case of EW is used since methodologies, and findings of different disciplines are not well linked to provide a holistic understanding of the notion of EW as dispersed yet important heritage. A more cohesive paradigm of how to study and communicate dispersed heritage represents a complex challenge, which may only be overcome through interdisciplinary and cross-cultural collaboration.

GVCHE for EW is an extension of an existing scientific EW platform (Solina, 2018; Oblak et al., 2019). As presented in the scheme (Fig. 5), such complex repository of research documentation organized using CIDOC/CDI (International Committee for Documentation / Common Data Index) standards, can be used as a primal resource for digital heritage interpretation and other audio engagement deliverables. Depends on the required level and means of interactivity, XR experiences, applied games, and 3D printed replicas/reconstructions could be created based on 3D assets and other data across different heritage interpretation environments: on-site, off-site, and on-line. For example, AR experiences could augment heritage parks and living cultures in situ. On the other side, virtual museums using VR could be available on-demand on-line or in hybrid spaces, such as at museum exhibitions. Stakeholders who could utilize the scheme for audience engagement may be content providers, including GLAM (Galleries, Libraries, Archives, and Museums) and other heritage institutions. Based on their audience research results, they could create inclusive content for all in collaboration with tourism, educational, and community sectors. In addition to general audience engagement, GVCHE is intended to be a valuable resource and a sharing platform for scientific studies across various, even non-heritage disciplines, such as hydrology and geology. Traditional research outputs could enrich the scientific part of the platform. However, non-traditional could contribute to audience engagement endeavours also in the form of a franchise.

This framework for documenting and communicating dispersed heritage represents the basis for heritage preservation, and inclusive audience engagement, as well as for policy making and budget management. Particular segments could partially be understood as working packages or projects. In the next stage, smaller research projects may be developed to investigate different elements of the proposed scheme, including the two case study proposals, discussed in this paper.

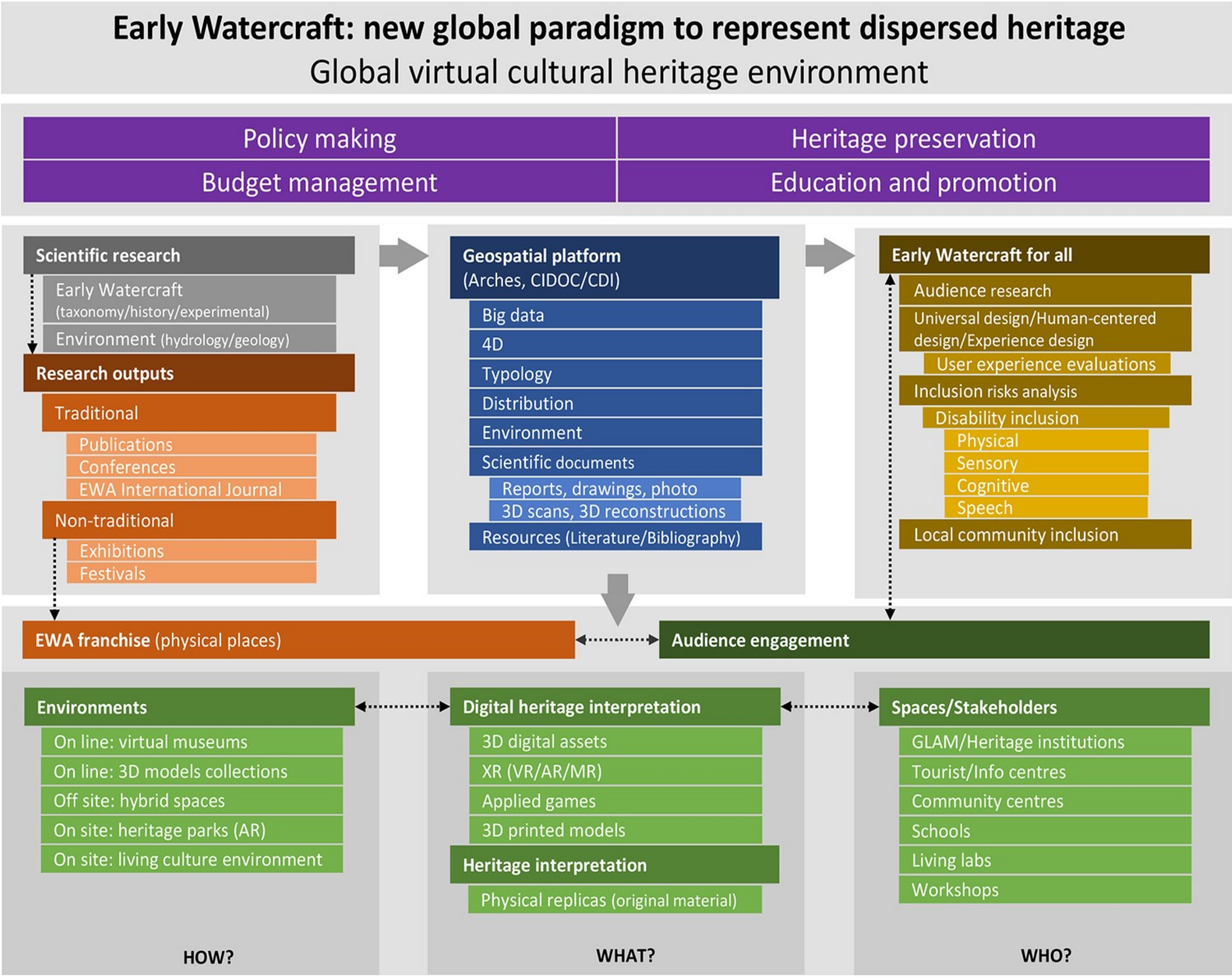


*Fig. 5. A proposed scheme of a GVCH of EW*

## Case studies proposal: inclusive audience engagement with Early Watercraft

Since EW is a shared and inclusive heritage, it can serve as a bridge between different continents, countries, and time zones. In this context, dispersed heritage can be used as a testbed for creating a unique multi-user experience through immersive collaborative game design focused on availability, accessibility, and connectivity.

The proposed model contains the use of data images and/or 3D scanned assets as a scientific input for CAD (Computer-Aided Design) reconstructions. The 3D models are then texturized using available libraries to understand the material used in EW (wood log, skin, bark, stems, etc.) better. Once 3D CAD models combined with GIS (Geographic Information System) environment are created, polygonized 3D models can be generated for the use in XR. In order to develop an inclusive and meaningful gamified experience, a user interaction with 3D assets must be well designed. These low-cost and transferable solutions of short gamified XR heritage experiences are inspired by indie games, a genre of simple computer games developed by independent authors. They can also be integrated into an MMO. Alongside the EW platform, the games will be accessed from various locations, including museums, interpretation centers, and schools as portable pop-up experiences. The framework will first be developed and tested using the two case studies in Slovenia and Australia. The framework aims to be applicable to other dispersed heritage content, too.

When considering inclusion and accessibility, the already mentioned extensive reference list with guidelines on disability-friendly gaming experience for diverse aspects of disability will help us face the challenging task of such highly interdisciplinary work.

The key feature of our design approach will base on adaptive experience which could be tailored on the spot to the needs of an individual user, even if part of a group. In practice, that means the ability to modify, not only difficulty of the game or controls (e.g. for diverse cognitive abilities), but also add/remove or rearrange specific on-screen features such as subtitles, interface size, color and font settings for color blind or visually impaired players and also adjust/change input method such as controller or keyboard/mouse binds.

The rule of two out of three will be pursued when creating XR experiences, meaning that all the information will be provided in at least two different forms out of three (visual, audio, haptic), which will enable accessibility also to those with visual or hearing impairment.

For intellectually impaired, the design will be such to be easy to comprehend, with the use of simple, clear language, narrative structure, tutorials, save game features and assist modes such as assisted steering or a co-pilot cooperative mode, where an able-bodied player can join in, as an alternative.

Some excellent solutions to be explored and incorporated into the platform for the two case studies will be as follows:

a) complete audio navigation for visually impaired; b) a complementary ALT-text for images; c) additional audio descriptions to all visualizations; d) videos with captions for deaf and hard of hearing; e) an easy-to-read content; f) gamification with easy-to-play options for intellectually impaired; g) opportunities for haptic experiences; h) inclusive storytelling as a part of heritage interpretation; i) inclusive and participatory pedagogic approaches. The core idea behind this holistically inclusive approach is the idea of Universal and Inclusive Design. That is, only when the needs of most vulnerable groups are addressed and the information is provided in multiple forms, everyone else will benefit from the experience, be it elderly, parents with children, temporarily injured, while fully-abled will benefit from enriched heritage experiences and multiple solutions to choose from.

The prototype will thus intend to incorporate all of the above elements within a simple experience of a building or riding an artifact. To illustrate, a potential scenario could engage users by accomplishing simple tasks such as transporting cargo and passengers (other players) while facing various environment-based challenges. Overcoming those challenges will be possible through direct co-operative play by a team of players, or a single player with indirect, optional help from an offline friend through various shared boosts, gained through simple knowledge-based side-quests such as quizzes, and multiple mini-games, tailored to a specific player and their needs.

**Case 1: Late mesolithic logboat from Hotiza, Slovenia**

In the first case, an EW archaeological artifact from Slovenia will be used. In 1989, in the gravel deposit of the river Mura near Hotiza, an oak logboat was found. Radiocarbon analyses date the vessel to the end of the 7th or beginning of the 6th millennium BC, which allows us to set it into the Late Mesolithic. It represents a find that is exceptional in its size, choice of wood, technological solutions, and, most importantly, its age (Erič and Nemec, 1993/94; Erič and Kavur, 2012).

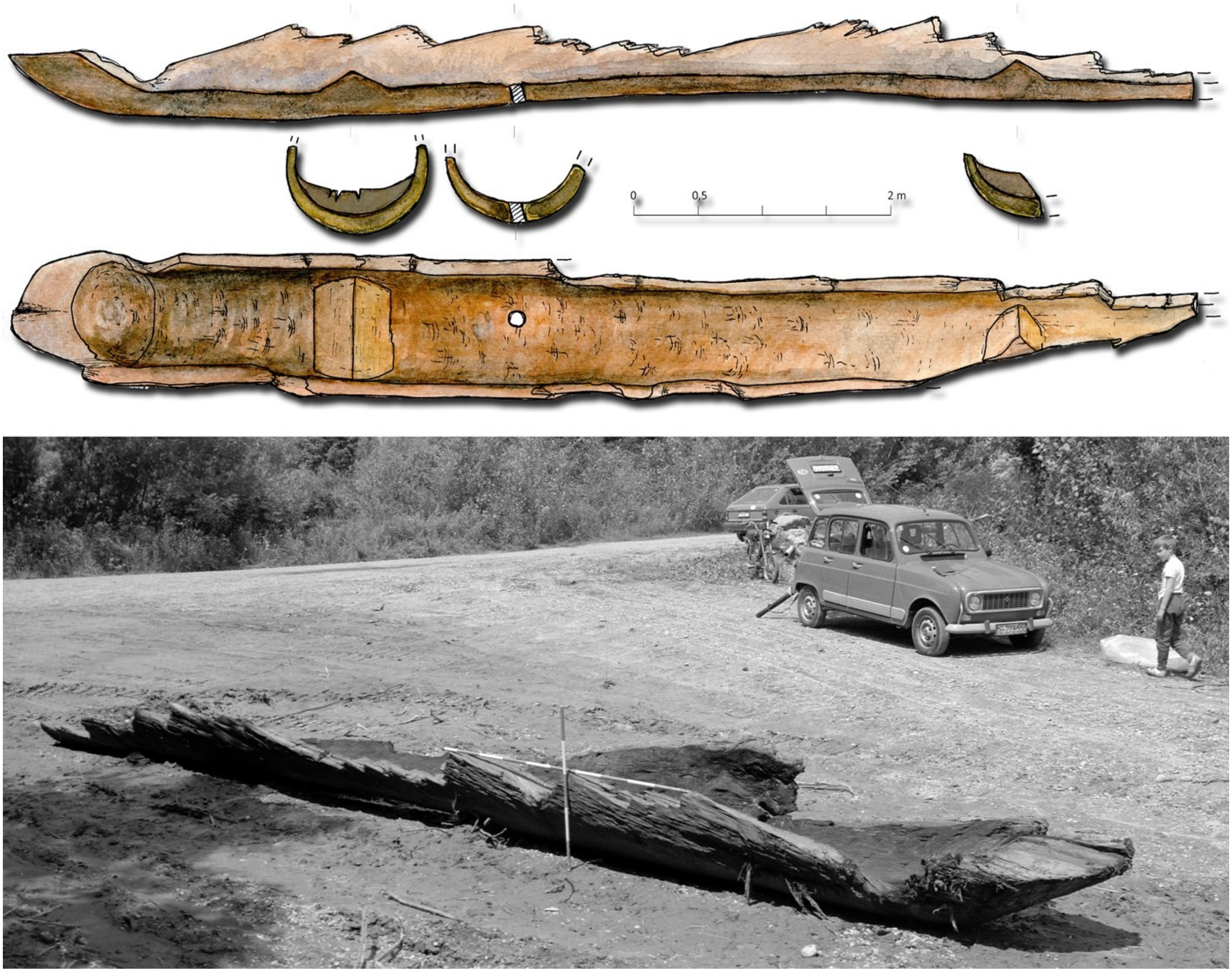


*Fig. 6. Bottom: Examine of Hotiza logboat late June 1990 (© Ivan Tušek). Top: Colorised technical drawing of logboat (© Miha Erič based on the technical drawing made during site examine by Marija Lubšina Tušek in 1989)*

The logboat was severely damaged, as it was repeatedly grabbed by a gravel basket, breaking part of the sides and part of the bow. The preserved length was 9.34 m, width up to 1.10 m and height up to 0.70 m. The average thickness of the bottom was 17 to 22 cm, and the sides gradually thinned from the bottom to the top, with an average width of 5 to 11 cm. About 5 m from the preserved forage, the trunk was concave in length, and the resulting negative gap was up to 15 cm high. About 2.5 m from the preserved feed, a transverse rib was constructed to strengthen the hull. The ribs were triangular in length, about 60 cm wide and 35 cm high at the bottom. In the cross-section, it adapted to the shape of the vessel and lifted towards the sides. A second, similar rib was made about 8 m from the preserved stern, but more than half were missing as the boat was already severely damaged in this part. Approximately 4 m from the preserved feed, a 14 cm diameter round hole was drilled into which a softer wood plug was inserted (Fig. 6).

From the archaeological point of view, the logboat from Hotiza is, by itself, an isolated finding. It has less studying potential if we treat it without comparison to the other similar artifacts across Europe and the world within the same timeframe. As the logboat from Hotiza is the seventh oldest known in contrast to the other dated logboats around the globe (Erič, Lazar, and Stopinšek, 2017) – the only logical study which could be done is to compare its analysis to other logboats and types of EW.

Ten years later, in the early 2000s, when computer hardware, CAD and visualization software became more accessible, selected EW artifacts, such as the logboat from Hotiza, were re-documented in 3D for further study and communication. With the help of Art Rebel 9 (AR9),[3] a pioneering 3D visual communication company from Slovenia, a reconstruction of this logboat, as well as its original condition, was recreated as a 3D CAD model. Both models were further interpreted in a pre-rendered animation, displaying the change from the found condition to the virtual reconstruction in the time of use. A decade ago, texturization was very limited as computer-generated graphics were not as developed as today. Based on AR9's 3D documentation from a few years ago, the logboat from Hotiza has been recreated again by LaniXi DeviantArt, a firm for archaeological visualization (Fig. 7) together with drevak from Ljubljanica river basin e.g. Fig. 8).

This proposal aims to contextualize further the virtual 3D representation of the logboat from Hotiza as a gamified XR experience. The contextualization will use a storytelling approach. A background scene will be created based on cultural and geological scientific data about the environment when the logboat was in use.

*Fig. 7. A preliminary (beta) 3D reconstruction of Hotiza logboat (© Lailan Jaklič – LaniXi art)*

**Case 2: Indigenous watercraft, Australia**

The second proposed case study is focused on digital preservation and interpretation of the EW of Indigenous living cultures of the Australian continent and nearby islands. Indigenous Australia has the oldest living culture in the world. It comprises over 250 Language Groups (or Nations) and is dated as far back as 65,000 years (Langton, 2018). Each Nation should be considered as a separate country in its own right, run by different rituals, customs, and lore (Australian Government, 2020). As

[3] http://artrebel9.com

per the 2016 Census, 3.3 % of people in Australia identify as Indigenous Australians—the Torres Strait Islanders and the Aboriginal People (Markham and Biddle, 2018).

*Fig. 8. Weddings on extended logboat drevak on Lake Cerknica, Slovenia (© Heritage House Cerknica [left]); A 3D model of an extended logboat (© Lailan Jaklič – LaniXi art [right]).*

Indigenous beliefs stem from the values that we must coexist with the land, animals, and water. Sustainable living and interconnectedness are the foundation of the culture, and so when creating tools, food, or equipment, nothing would be wasted (Behrendt, 2015). The land was respected so much that smoking ceremonies and water blessing rituals would be conducted when welcoming people on to country, in order to provide spiritual protection over people and cleanse their spirit (Tribal Warrior, 2019).

Aboriginal and Torres Strait Islander culture was not written; all knowledge was passed down through story or song once a person was of the acceptable age and maturity level. The art in which these stories and knowledge were shared was called Songlines or Song Cycles, and as people grow or marry, so does their Songline (Horton, 1994). Indigenous technologies are still being discovered today due to colonizers overlooking Indigenous creativity, their knowledge of land management, as well as the hidden history within the Songlines.

As well as having the oldest living culture in the world, the Indigenous people of Australia are shown to be the first engineers of the world. The earliest relics of tools belong to the Indigenous Australians, and coincidentally the first evidence of intercontinental sea traveling (Arthur and Morphy, 2019). Researchers attempted to mimic the bamboo raft that traveled—most likely sailed—between Sahul (now known as Australia and Papua New Guinea) and Sunda (South-East Asia and Melanesia), using bamboo, oars, and sails. The approximate dates are assumed 44,000–50,000 years ago (Florek, 2012).

There is little information currently available predating the single and double outrigger canoes. As stated above, Indigenous people used the resources around them with no waste. Across Australia, Indigenous people used the materials at hand to create and build watercraft with the resources available to them (Arnold, 2015).

In the north of Australia, Arnhem Land, and the Cape York Peninsula, sewn bark canoes were used more than 3,000 years ago (Florek, 2012). Further along, in the Kimberley's and Western Australia, was the triangular log rafts typically made from mangrove trees. In Queensland, seafaring bark canoes were created at least 8,000 years ago. Victoria and New South Wales used bark canoes approximately 7,000 years ago (Florek, 2012). It was common for canoes to carry a fire that was protected by layers of sand within the boat to assist with navigation and resettling once the desired location was reached (Arthur and Morphy, 2019).

The Australian National Maritime Museum's (ANMM) Australian Register of Historic Vessels (ARHV) records several Indigenous watercraft and has a section 'Indigenous watercraft of Australia'. It provides an essential resource of all known types of Aboriginal and Torres Strait Islanders' watercraft (ANMM, 2018a). Curator David Payne argues these watercraft "could be living examples of the origins for the evolution for boats" (Payne, 2018). Until now, 46 types of watercraft from ANMM and museum collections across Australia have been registered with a photograph and other available relevant metadata (Fig. 9). Fourteen collection items have been mapped within the National Maritime Collection using the Getty Thesaurus of Geographic Names (TGN) based on their manufacturing or related place. The map is a useful resource for locating data. However, its purpose is mainly for reference only, rather a geographic information system with exact coordinates (ANMM, 2018b). Following the ARHV's listing of Indigenous watercraft of Australia, our case study intends to digitally interpret one or more recorded examples using gamified Extended Reality experiences. The main aim is to communicate Indigenous design and engineering heritage in a novel and inclusive way not only to younger generations of Indigenous and Non-Indigenous Australians but also to audiences overseas.

Due to its capability for storytelling, XR has the potential to become a widely used medium for communicating Indigenous knowledge. A relatively small number of artists, designers, and researchers have already started to explore XR. Virtual Songlines, founded by an Indigenous artist Brett Leavy, Bilbie Virtual Labs, is a great example of using new technologies to explore historical events or information. Virtual Songlines is a Virtual Reality simulation that has mapped known data of pre-colonization Australia landscapes. It allows a user to interact with the landscape and join in activities from Indigenous Australia, things such as hunting, foraging, corroboree, and canoeing.

Another example is Collisions, an 18-minute VR story directed by Lynette Wallworth. The film recorded as a 360-degree video features Martu Elder Nyarri Nyarri Morgan and his story about nuclear testing in his traditional lands in Western Australia. Among others, this artwork has been presented in various museums including ACMI (Australian Centre for the Moving Image) in Melbourne from the 7$^{th}$ of October 2016 to the 15$^{th}$ of January 2017 (ACMI, 2016) and at the Powerhouse Museum (MAAS – Museum of Applied Arts and Sciences) in Sydney from the 15$^{th}$ November 2019 to the 30$^{th}$ of June 2020 within the Linear exhibition (MAAS, 2019). Along with Collisions, the Linear exhibition features another XR experience. Interactive Wiyanga Bamulra Butt Butt Gurinyi (Mother Earth's heartbeat) utilizes AR on a provided tablet and virtual assistant (voice) in order to tell a personalized story about the object displayed. Users can interact with the exhibit through posting questions, which are then answered by a virtual avatar. The experience was created by Indigenous entrepreneur Mikaela Jade's Indigital in collaboration with Bilbie Virtual Labs.

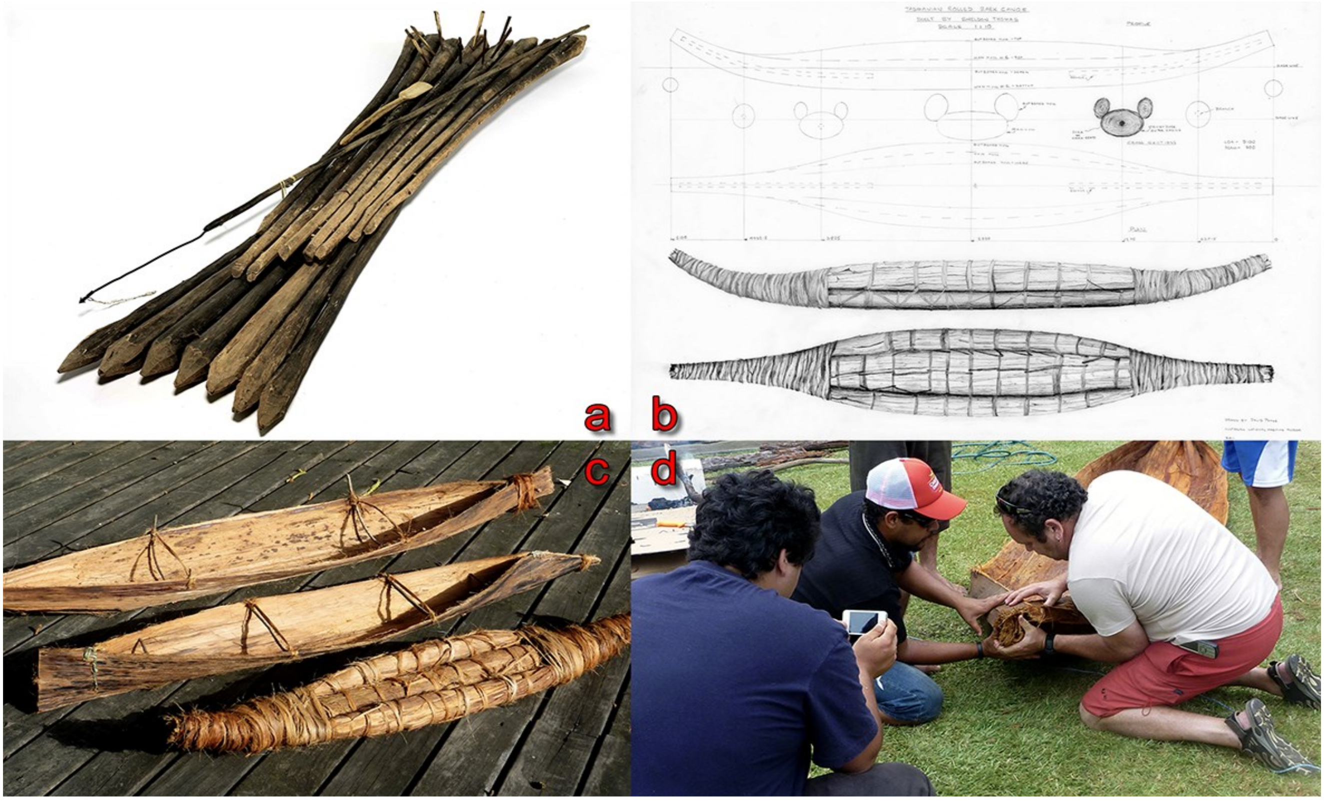


*Fig. 9. a. Kalwa. © Andrew Frolows (ANMM Collection 00001700); b. A Tasmanian ningher built by Sheldon Thomas in 2011, now on display at Melaleuca in Tasmania. © David Payne; c. Nawi, gumung derrka and ningher models. © David Payne; d. Paul Carriage from Ulladulla LALC brings an end together. © David Payne (Australian National Maritime Museum).*

For providing a suitable framework for communicating Indigenous watercraft of Australia as gamified XR experiences, the project proposes the content to be publically available on the EW GVCHE platform via a localized digital Indigenous-led platform Our Songlines. The platform is designed to share Australian Indigenous culture with Indigenous and Non-Indigenous audiences to bring about understanding for the First Nations People. Our Songlines platform addresses the gap of limited information shared with wider audiences about the history of pre-colonization. The platform is an educational tool, which allows a person to view Indigenous sites, tours, and cultural business while also teaching users about culture and history. Our Songlines promotes Indigenous knowledge through images, maps, social media, and story. It is targeted towards the wanderlust, the educators, the truth seekers, and the adventure finders. There is a potential for the use of EW to shape a new adventure and share the education of the ingenuity of Indigenous Australians through the interactive map and XR experiences. It will be important to explore ways of representation of Songlines for people with diverse impairments. For instance, the interpretation of auditory stories to reach deaf and hard of hearing people will need to be given in visual, textual, and haptic forms. Whereas, intellectually impaired will benefit from textual and visual representations carrying an easy-to-comprehend story.

In the first stage, a set of interviews and focus groups with Indigenous communities will be conducted following relevant documents such as First Peoples: A Roadmap for Enhancing Indigenous Engagement in Museums and Galleries (AMGA, 2018), the Australian Indigenous Design Charter (AIDC, 2018), and similar. Ethical clearance will be sought as well following the National Statement on

Ethical Conduct in Human Research (NHMRC, 2007, updated 2018). The results will inform the decision which watercraft from the ANMM's Register of Indigenous watercraft of Australia is most suitable to be 3D digitized or 3D reconstructed for the first gamified XR prototype and what is the proposed scenario.

The XR prototype will later be developed and tested on user groups with various abilities, including Indigenous and Non-Indigenous museum visitors. In order to create jobs and a sense of belonging, it is planned to co-develop the experiences with the members of local Indigenous communities. Aboriginal and Torres Strait Islander designers and developers will primarily be invited to create the games. If required, training to upskill them may be established.

Our Songlines is an online platform that can partially feature Virtual Reality content on demand for users who own their own HMDs (Head-Mounted Displays) and supportive equipment. Besides, a mobile pop-up museum XR experience could be developed in a box to be easily transported to regional museums, schools, and community centers, as well as to hospitals and retirement villages to users with limited mobility. 3D printed props in a physical form of scaled EW digitized/digital reconstructions may be used, especially when addressing visually impaired users.

## Discussion and Conclusions

The proposed project aims to investigate digital representations of dispersed heritage irrespective of its context and location as well as engaging opportunities for all, including people with diverse impairments. In this paper, a systematic approach for developing inclusive gamified immersive experiences from a publicly available scientific repository is proposed. The proposal will be tested on the EW GVCHE platform.

EW is one of the most important early technical human achievements mutual to all past and living cultures inhabiting near the water body worldwide. The proposal addresses the challenges and opportunities that this dispersed heritage faces to become more recognizable and unified on a global scale. Firstly, EW has been relatively well studied by various distinct scientific disciplines such as archaeology and anthropology/ethnology. However, instead of lacking joint effort, a more interdisciplinary and cooperative approach is needed to understand the holistic notion of EW. A collective forum for a shared discussion may be a valuable foundation. Secondly, EW projects are often limited to local initiatives, yet, more cross-cultural strategies may have a bigger impact on cohesion. Thirdly, a smooth knowledge transfer from science to wider audiences should be provided through actions of engagement to ensure science to stay relevant and for heritage to become a resource of empowerment and inspiration for future generations inclusive of all people.

The proposal of the geospatial digital platform GVCHE introduced herein is perceived as a holistic platform aiming at addressing these challenges. It aims to connect scattered scientific data from different disciplines. It represents an ambitious nexus between archaeology/anthropology, heritage, digital technologies, audience engagement, and disability. As such, it encapsulates a complex interdisciplinary approach, which already in itself brings multiple challenges. The success of the GVCHE will depend on many collaborators.

Furthermore, the GVCHE platform proposal explores ways of making the invisible and dispersed EW heritage noticeable. Even more, it may represent a valuable platform for reaching out to wider audiences regardless of their (dis)abilities. Audience engagement strategies are proposed to be integrated into the GVCHE through the creation of non-scientific heritage content following principles analogous to Universal Design and Design for All. It is vital for all outreach activities to be tailored for users with different abilities rather than only consider the general public. When the needs of most vulnerable groups of people are addressed, everyone can benefit from any design, including heritage. Inclusive gamified XR experiences have been identified as a novel approach to the digital interpretation of dispersed heritage. Thus, relatively low-cost indie games in forms of XR experiences will be tested on two different cases: an archaeological artifact—a Late Mesolithic logboat from Hotiza in Slovenia, and Indigenous watercraft from Australia. The results of this research will represent a valuable study of how to communicate dispersed heritage to both scientific and non-scientific audiences inclusively. The finding may bring a useful methodological contribution to the digital interpretation of dispersed heritage.

To conclude, this proposed paradigm scheme represents not only a holistic but also a relatively complex research initiative. Anticipated challenges identified already in the proposal development are mainly related to interdisciplinary and cross-cultural collaboration as well as to technical limitations and funding resources. To minimize risks, a great deal of time is dedicated to building partnerships on various levels. In addition, the two proposed case studies provide a manageable terrain for initial investigation of the proposed framework from both technological and funding perspective before the suggested audience engagement strategy can fully be integrated into the GVCHE. Seed funding will first be sought before applying for larger grants.

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# Telling Stories of Site

## The Case of Lifta

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**Abstract:** The life cycle of many cultural heritage sites typically includes a long history of transformations since its inception, involving additions, adaptations, destructions and rebuildings. Such transformations produce one challenge for archaeologists, who excavate the layers of the site's remains and conject development, and another for conservationists who identify, preserve and perhaps reconstruct its presumed authentic state. Moreover, these transformations are not limited to that of physical forms. Indeed, a cultural heritage site is always a place for past activities, experiencing generation and loss of different uses and points of views with each change of hands. These cultural and historical multiplicities then, present a challenge for any cultural heritage practice aiming to make its history and narratives available to a public audience.

This paper introduces a recent cultural heritage project in the disputed and evacuated village of Lifta near Jerusalem, to discuss how contemporary technology tools can intervene in a complex social and political context. The pipeline of cultural heritage practice includes field-based data collection, processing and interpretation, and distribution, in which technological tools are critical. For data collection, the use of photogrammetric capturing and audio-video recordings, for example, are non-intrusive, and are efficient means to rapidly collect forms and events on the site. For data processing, an online platform can help team members practice sharing geo-located data and design multifaceted representation of the site in question. And for the public audience, narratives about cultural heritage can be developed through interactive digital tools such as game engine environment in the service of distributing multimedia contents (such as 3D capture, video, and audio for different sensory experiences), embedding different stories that represent multiple points of view, and accommodating the participation of those who are interested in making comments and sharing their personal points of views.

***Keywords:*** *archaeology—digital heritage—multiplicity of narratives—storytelling*

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## A Brief History of Lifta

The village of Lifta, whose buildings, caves, agricultural terraces, and spring, hold a long and conflicted history of inhabitation and evacuation, ritual and culture, is located at the western entrance to the city of Jerusalem, nestled between two highways and mountain slopes. Surveyed and excavated numerous times from the beginning of the archaeological study of the Land of Israel at the end of the nineteenth century, (Galor, 2011, p. 11) and up to the most recent conducted by the Israeli Antiquities Authority and completed in recent years, the stories, histories and narratives of Lifta are complex and varying, and at times contested and contradictory.[1] The history of the village, as it is told today by official representatives of the State of Israel, finds its origins in the text of the bible.[2] A common proposition, though somewhat contested, suggests that a site mentioned in the Old Testament, 'Mei Neptoah,' which is marked in the Book of Joshua as one of the boundary points between the lands of the tribes of Yehudah and Binyamin, is in fact the spring of Lifta.[3] This relies on the assumption that the name 'Mei Nephtoah' was derived from the name of the 13th century Pharaoh Merneptah. As the argument goes, "the "Wells of Merenptah which are in the hills" is the group of springs at Lifta, near Jerusalem, and were so named by Merenptah after his victory over the Israelites, whom he compelled to evacuate Jerusalem itself." (Yurco, 1986, p. 213) The settlement itself, as noted, may have already existed as early as the Iron Age (58–1000 BCE) in the place of the 'Neftoach' or 'Mei Neftoach' neighborhood. In addition, the Roman Jewish historian, Josephus, provides information about the destruction of a large settlement during the Roman suppression of the Great Revolt of 66–70 CE at the end of the Early Roman period, which some scholars believe to be Lifta[4] (Moshe, 2012).

During the Ottoman period, Lifta was renewed and developed into a modern village, first through the construction of an industrial zone that served its vast agricultural areas. At the same time, some of the village's natural caves were converted into dwellings, mostly on the upper part of its northern slope. New buildings were added north and east of the core, which used more novel construction techniques and organization. Through their longitudinal construction sequences, these would also come to reflect the clan ties between the various residents. Inner courtyards between several such related buildings would become public spaces that were used and oriented towards the families that resided around them. Later, various 19-century travelers and pilgrims would depict a small village hiding deep within a valley, surrounded by olive trees and wheat fields. Victor Guérin, a French explorer and amateur archeologist, described in the late 19th century a village "sitting on the sides of a rocky mountain… in the shape of an amphitheater," and having "hundreds of inhabitants, all Muslims."[5] (Moshe, 2012)

[1] Various studies explore the battle of narratives around the question of the Israeli-Arab war of 1948, and the depopulation of Palestinian villages and spaces. For instance: Kadman, Noga, Dimi Reider, and Ofer Neiman. *Erased from Space and Consciousness: Israel and the Depopulated Palestinian Villages of 1948*. Indiana University Press, 2015.

[2] The historical narrative presented draws largely on the comprehensive work conducted by Dr. Michal Moshe as part of the archeological survey conducted by the Israeli Antiquities Authority. See: Moshe, Michal. "The Village and House in Lifta: An Architectural Historical Survey" in Israeli Antiquities Authority, Conservation Administration, *Lifta Survey (2014-2017)*. All translations are of the authors. http://www.iaa-conservation.org.il/Projects_Item_heb.asp?site_id=3&subject_id=6&id=180

[3] Chapter 15 in the book of Joshua describes the limits of the land allocated to the Judea Tribe, and reads in verse 9 that "the border was drawn from the top of the hill unto the fountain of the water of Nephtoah, and went out to the cities of mount Ephron; and the border was drawn to Baalah, which *is* Kirjathjearim." Today, while the village's remains are recognized under the name Lifta, signs located at the site and placed by Israeli authoreties mark the spring as Mei Nephtoah (the waters of Nephtoah).

[4] Josephus Flavius quoted in Moshe, 2012.

[5] Guérin, Honoré Victor. Description géographique, historique et archéologique de la Palestine, accompagnée de cartes détaillées. Paris, L'Imprimerie Imp., 1868, quoted in Moshe, 2012.

*Fig. 1. View of Lifta from north-west towards Jerusalem; drone photo by the authors, 2019*

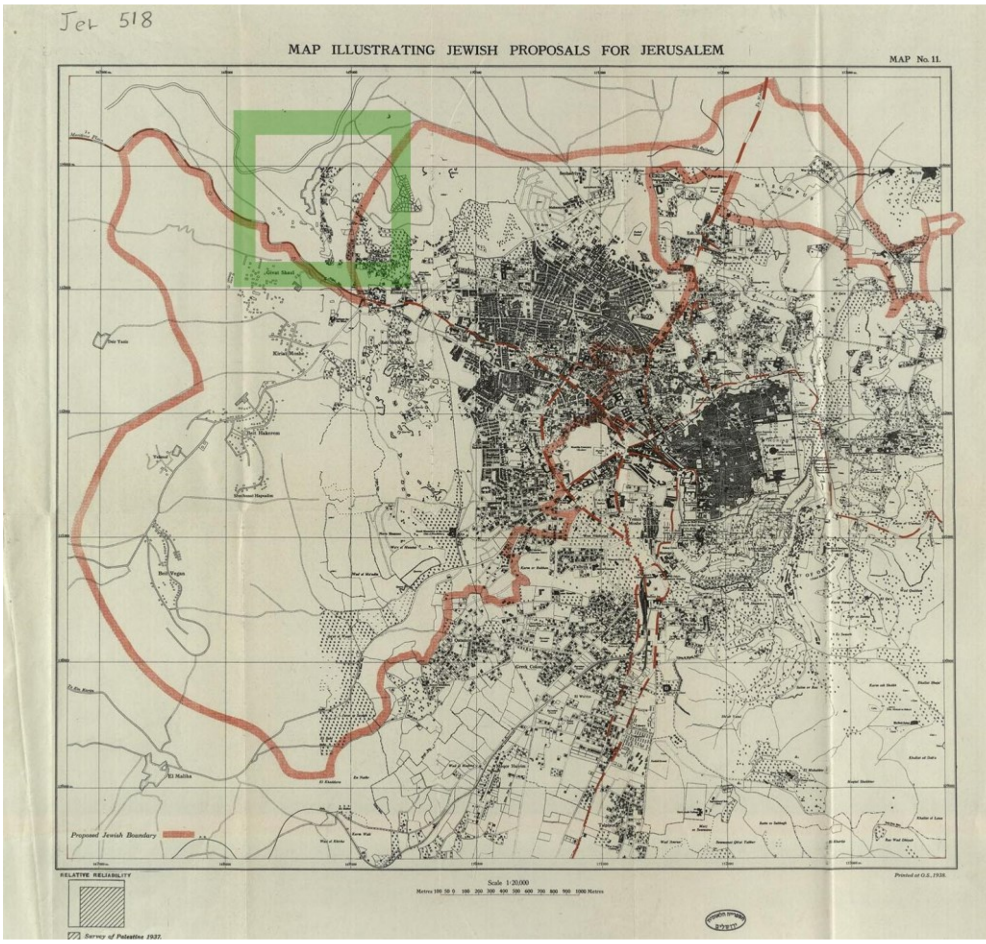


*Fig. 2. Map illustrating Jewish proposals for Jerusalem, Survey of Palestine, submitted to the Woodhead Commission, 1938. Lifta, marked in the green square, is outside the Jewish proposal limit. (Source: The Eran Laor Cartographic Collection, National Library of Israel).*

The period of the British Mandate of Palestine (1918–1948), following the collapse of the Ottoman Empire, brought development and change to many of the region's settlements, particularly due to the growing connection between the village and the city of Jerusalem which was also expanding rapidly at the time. This connection and growth in size also cultivated changes in the traditional village structure, in the design of the village's buildings, as well as in building technologies (Mohse, 2012). In 1924, Lifta was first included in Jerusalem's jurisdiction, with building laws, enacted during that year by the British government. This attempt to create uniformity, order and standardization of building according to organized principles, has brought a modern and bureaucratic character to what has been until that time a kind of organic development of the village, and put a stop to the correlation between the village's evolution and its residents' needs.[6]

In 1929, during the Palestinian riots of that year, there were several clashes between Jewish residents of Jerusalem and the Palestinian residents of Lifta. This began a period of sporadic conflicts and clashes. (Cohen, 2015, p. 98) In 1936, a Jewish newspaper reported on the establishment of a police station near the village, presumably as a reaction to the continuous clashes.[7]

In 1948, after the first Israeli-Arab War, the village's Palestinian inhabitants were either forced out and evacuated or escaped to East Jerusalem and other West Bank villages, as the village and its environs were taken over by Israeli military forces.[8] Under Israeli rule, Lifta has become somewhat reflective of both the nation's ambitions, its origins, and do a degree, its future. In the first decades after the state's establishment, the ruins of Lifta, as other places, have become sites of inspiration for the cultivation of biblical myths and images that visualize the connection between the Jewish people and the Land of Israel, to the point that it even served as a filming location in the 1958 production of the Hollywood epic *Ben-Hur* (Amir, 1958). At the same time, and during the 1950s, Jewish immigrant families from Yemen and Kurdistan were resettled by the Israeli government in the then empty structures in the village, only to be removed by the government 25 years later, making them effectively the last inhabitants of the site.

The most recent development in Lifta's contested history, dating to 2006, is the submission, approval and suspension of plan 6036 by the Jerusalem municipality: a new urban plan seeking "to turn Lifta into a luxury commercial and residential development exclusively for Jewish expatriates." The proposed plan offered, among other things, the construction of "268 luxury housing units, a large shopping mall, a tourist resort, a museum and a luxury 120-room hotel." (Raffoul, 2015) The execution of the approved plan, however, was halted after a long legal battle conducted by former residents of Lifta, and the Save Lifta Coalition, a group of activists from both Israeli and Palestinian communities, one of whom is the architect Shmuel Groag, one of the authors of the original plan.

Today, Lifta stands as one of the only Palestinian village that was neither completely demolished nor resettled by a Jewish-Israeli population following the Israel-Arab war of 1948. Its remarkable condition, given its history, is a unique testimony of "an architectural and agricultural culture that has been

[6] Moshe provides a brief description of the kind of rules that were enacted, limiting the size of the village, the distance between buildings, the size of plots, etc.

[7] *Davar (דבר)*, June 8, 1936, pg. 7. Historical Jewish Press (JPress) of the National Library of Israel Archive.

[8] For a thorough account of the evacuated and destroyed villages in the 1948 war, see: Khalidi, Walid, ed. *All That Remains: The Palestinian Villages Occupied and Depopulated by Israel in 1948*. Washington: Institute for Palestine Studies, 2006.

prevalent in the Middle East for thousands of years but was destroyed in 1948 or has undergone modernization and development, thus losing any ancient cultural-historical characteristic."[9]

This recent history of conflict and destruction finds echoes in its current daily state, when former Palestinian residents come to celebrate various events and commemorate their ancestors' presence, or during frequent clashes between orthodox Jewish men who claim ownership over the village's spring, and Israeli women who seek to bath recreationally in the cool waters.[10]

After decades of abandonment, a history of both battles, prosperity, destruction and mutual life, Lifta has transformed into a rich habitat for many plants and animals, some of which are quite rare, protected and endangered. Its importance, even today, is diverse: it is a natural reserve and a green lung adjacent to Israel's capital and largest city; a site used daily by visitors and locals, whether due to its ruined beauty, or the cool waters of its spring, serving both secular individuals looking to escape the summer's heat, or Jewish orthodox men, who use it as a mikveh,[11] and claiming it, through their actions as an exclusively male space; a symbol of Palestinian memory, resistance and national aspiration; and perhaps the last place, holding through its emptiness, the possibility of a mutual life in a contested land.

The village's past and present offer an opportunity for the creation of a unique kind of scholarship. Due to the site's complex and often ignored or manipulated history, there is an important potential role for historical research that exposes both the site's various pasts and the contentious relationship between different narratives. Lifta is at once local and representative. It represents transformations, attitudes and cultural shifts pertaining to the city of Jerusalem, the State of Israel, Palestine and the region at large. Exposing competing histories through new technology will demonstrate in a special manner that historical, material and cultural compositions of archeological sites generally contain a multiplicity of narratives accumulated through time.

## Lifta Workshop: Digital Archeology / Virtual Narratives

In June 2019, a collaborative workshop brought together the resources and expertise of the MIT Department of Architecture and the Ben Gurion University Department of Bible, Archeology and Ancient Near Eastern Studies, for undertaking an interdisciplinary study of the material remains of Lifta. The collaboration was intended to build upon the intrinsic relationship that both disciplines share and differ in, in respect to notions and ideas of site, temporality and imagination. Indeed, both disciplines draw upon the material reality of a site presence in order to imagine it in a different time. While architects are preoccupied with the design and production of future scenarios, archaeologists are committed to the unequivocal determination of the antiquity of things. Still, both fields deal with the fundamental question of how to conjure up an image of a place, whether by recollecting lost events or by speculating about future possibilities. The collaborative workshop aimed to use both the affinities and gaps between the disciplines as productive in order to produce unique immersive representations of the site.

[9] "Save Lifta." http://savelifta.org/about-lifta/ (Accessed: 20 January 2020).

[10] See for instance: Hasson, Nir. "Men and Women, Religious or Not, Battle for Rights at Israeli Springs - Israel News - Haaretz.Com." https://www.haaretz.com/israel-news/.premium-men-and-women-religious-or-not-battle-for-rights-at-israeli-springs-1.6221515 (Accessed: 20 January 2020).

[11] A 'mikveh' is a water source, usually a bath that is used for Jewish ceremonies of purification.

Lifta and its varying narratives are symbolic of the war on material history in Jerusalem, conducted through archaeological excavation and polemical writing, rendering the ruins of Lifta a tool in geopolitical conflicts. Instead of letting an archaeological site in this region to constitute proof of precedence or ownership by any one nation, ethnic group or religion, this workshop, through design analysis and visualization methods, aimed at constructing a multivalent and complex model of the Lifta's past. Lifta thus becomes a site constituted of multiple layers of political, design, and cultural histories, representing a multifaceted narrative.

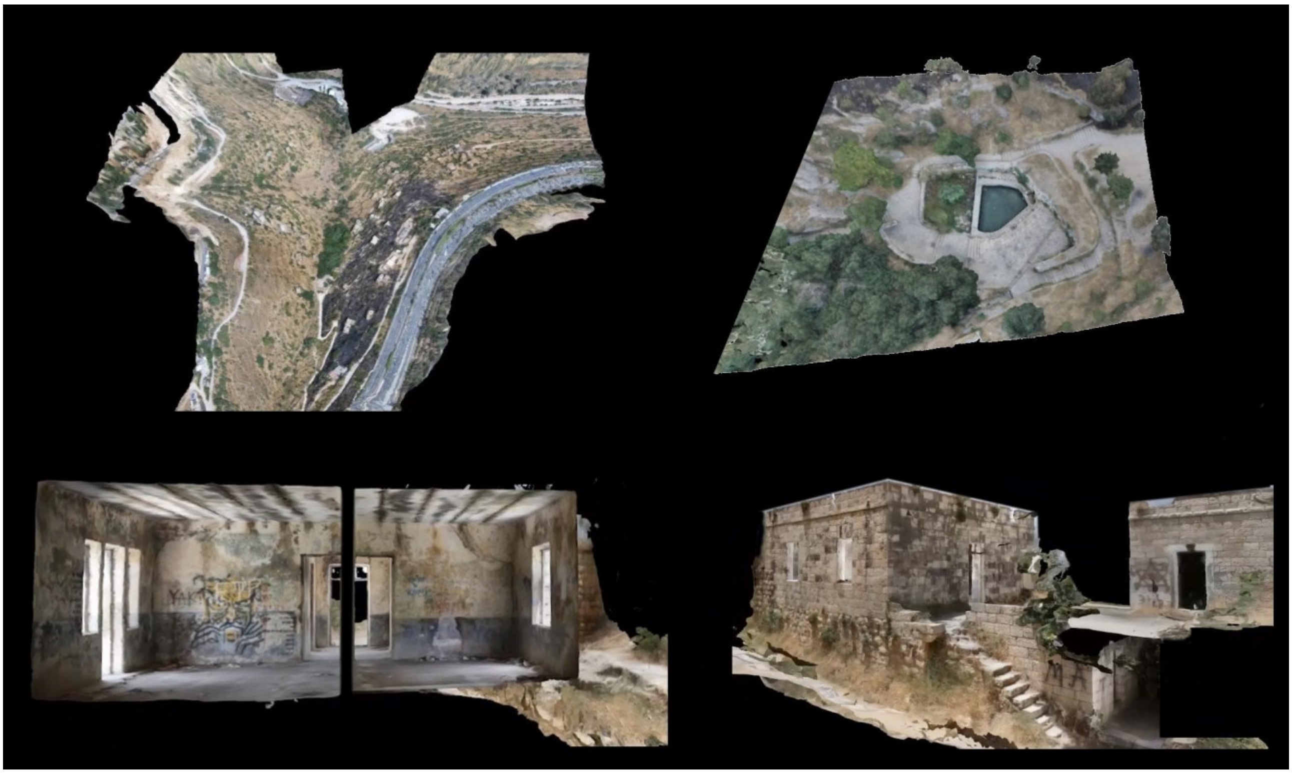

*Fig. 3. Examples of the 3D models captured at various scales by different participants: the valley of Lifta made from drone photos (top left), the area around the main spring near the valley's center (top right), a house interior (bottom left) and exterior (bottom right) located to the north of the spring. Those heterogeneous models and other media such as drawings, photos and videos were shared and composed in an online platform to create narratives of the site.*

The workshop asked students to participate in an interdisciplinary study of the evacuated village, and investigate through various methods the archaeological and architectural remains, as well as the various archives, narratives and stories told about the site. Working in groups, the students captured the site using ground and drone-based photogrammetry, laser-scanning, and produced 3D representations, digitally making available experiences that present a bricolage of Lifta's material remains, which are conceived as a pedagogical resource. By combining these 3D representations with an array of archival, historical and scholarly resources as well as audiovisual recordings of the events during the workshop, students of architecture, art, and urban planning, deployed interactive and immersive tools to create experiential installations of Lifta's contested terrain, in which they challenge both the linear and singular narratives of the site's past, as well as the traditional approaches to the study of conflicted histories.

## Collaborative Process

The workshop aimed to produce experiential representations of Lifta while engaging in a collaborative work process. Accordingly, the fieldwork included various partners and collaborators which contributed to a collective archive of Lifta, to be presented in an immersive and interactive platform. First, the workshop's development and the themes to be explored was done in close collaboration with a team of expert archaeologists, led by prof. Yuval Yekutieli and Eli Cohen who incorporated their method or "reading-out" stories from the site's material remains.

This was fundamental to the project's motivation to integrate surveying and storytelling of site. While the archaeological approach enriched the design of the experience, the workshop embraced the notion of collaborative archaeology, not deployed by a small circle of experts but rather crowd-sourced to other stakeholders as well as architecture students, and towards the public.

*Fig. 4. (From left to right) A Palestinian refugee leading a tour at the site, local people bathing at the main spring, archaeologist lecture, and a student participant recording the site after the natural fire spotted during the workshop.*

Other meaningful partners were the 'Save Lifta Coalition' which consist of activists of different backgrounds, including Palestinians and Israelis; including those who lived in Lifta, their families and descendants. Among them is Ya'akub Oda, a Palestinian refugee, born in Lifta and lived there with his family until the depopulation of the village during and after the 1948 Arab-Israeli War. Oda toured the village ruins with the workshop participants and told his story—the memories of Palestinian Lifta, before 1948. These are vivid stories of life in the village, the families, rituals and daily social life. Leading a group of students through the landscape, approaching the spring Oda recalls:

*"This area is our water system, this is what remains, and it is very important in our memory, to us the Liftawis, people can come here and clean and pray around this area, and women with jugs on their head would come to take water to drink… and here there was a huge strawberry tree with a shadow not less than 40 meters in diameter, villagers would come and sit under the tree and tell stories of their fathers."*

These testimonies stand in stark contrast to the official survey of the village done by the Israeli Authority of Antiquities, which naturally takes a more scientific tone in describing the site and its history. While the survey strives for objectivity, the oral history is subjective and intimate. Part of the challenge was to capture both.

Depopulating of the Lifta, first of its Palestinian population, happened a second time more recently, during the past couple of decades. This time of its Jewish-Kurdish inhabitants who were settled in the village ruins in the 1950's. Although the circumstances are different, here too are families who were evacuated from their homes and have their own personal perspectives on the ruins of Lifta. Yoni Yochanan is among the last Jewish settlers of Lifta, still holding tight to his family's house in the wadi, fighting for his right to the ground and his own evacuation. He too contributed his own stories to project and added another layer to the complex strata which is Lifta. Climbing up to Yochanan's house, students visited the house, which he is now renovating with his own hands, and without official permits, hoping to transform the Palestinian-origin structure into a hotel. He told of his roots in Lifta, proving another different perspective on the landscape:

*"After the war, the Arabs left the village, and our parents moved into the houses from Iraq and Yemen. There was nothing here, and after a few years they connected the houses to electricity.... There were 350 families in Lifta… Today, they want to make a new neighborhood here and destroy the houses, so we don't know what will happen (...) I think this place should become like a museum to the Jewish and Arab who lived here."*

Given these various accounts of the site, how does one capture the site's physical state along with its concealed narratives? Can an archaeological survey expand beyond its objective standpoint to include multiple material remains overlaid with multiplicity of stories? And if so, how to curate these experiences?

The workshop attempted to develop a methodology and technological framework to unravel some of these questions, by curating 3D scanned models and other audio visual materials to be choreographed and presented in a time-based, and geo-referencing manner to unfold narratives. This was done through two means: 1) Online Platform 2) VR experiences.

## Online Data integration and distribution platform

The Design Heritage (Nagakura et al., 2018) is an online collaborative platform to present 3D captured photogrammetric models along with other types of evidence about the site, open to the public to add multimedia data, such as archival documents, video and audio captures of onsite events and tours, as well as fieldwork documentation. The workshop used this platform to allow curation of storylines, which include different 3D models, onsite recordings, archival documents and notes. Through storylines, the site can be imagined from different points-of-view, focusing on varying aspects of its heritage experiences.

A community of users, whether students or civilian contributors, are invited to add their own created models to the platform, and to place them in the context of large areal model, which sits on the global coordinate system. This 3D map of the site accommodated detailed 3D models of the main spring and other community spaces as well as the interior and exterior of major houses captured on the site, while allowing the audience to navigate between different scales. Field notes and archival documents of photos and drawings were geo-referenced on the map to be brought up at relevant locations. It is also animated by the audiovisual recordings of a former resident touring on the site, onsite operation of the workshop participants, and the fire spotted on the site and evacuating visitors. The dataset in this map collectively conveys different experiences and narratives of the site.[12]

[12] A short introductory video on the workflow, from fieldwork to online platform, can be found online: https://www.youtube.com/watch?v=bMzPxYUcn1s&feature=youtu.be

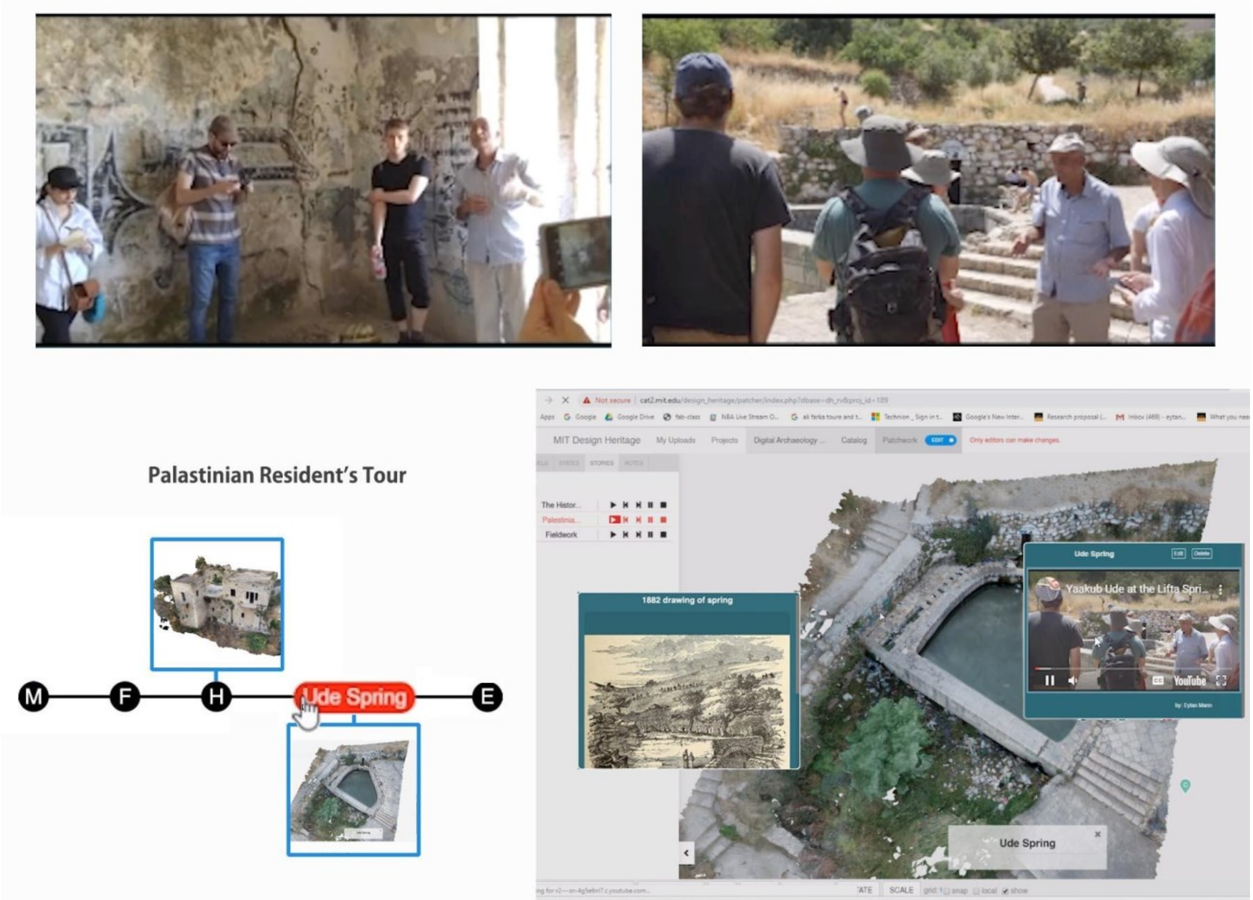


*Fig. 5. Top: Onsite tour with Ya'akub Oda, a Palestinian refugee from Lifta. Bottom left: A sequence of five 3D scenes composed in the online platform to trace the tour, including his talk in his former residence and the community spring where the villagers bathed. Bottom right: The screen shot of the 3D scene around the spring shows an integration of the photogrammetric 3D model with the video recording of the talk and a historic drawing, each geo-referenced to the locations on the model.*

In addition to this, the platform offers a set of tools to curate narratives and adds a new dimension to the traditional google-map-like platforms. For example, three storylines were put together on the platform during the workshop.

1. Historical photos: A collection of historical photographs and illustrations from various sources were uploaded to the platform and geo-located on the 3D models. Its sequence is designed to provide a sense of the place through the perspective of a photographer.
2. A Palestinian Life in Lifta: This sequence incudes the segments from Palestinian refugee Ya'akub Oda's onsite tour recorded in videos, with each geo-located on the 3D models.
3. Workshop Journal: The third sequence was used to manage multiple collaborators, and represents the story of the workshop's fieldwork itself. It includes the geo-referenced notes, photos, and videos collected and exchanged during the collaborative work and helped store, manage, share, and discuss the community's process.

## VR Curations

The student projects took another step further towards the creation of a visual, immersive and critical historiography of Lifta. In each of the three projects developed, the site and its various interlocutors, its archival resources, are all composed in the service of the narratives, through which Lifta's complex histories unfold anew. In that sense, the projects represent, though are in no way comprehensive, of the variety of approaches and scales that can be employed in the study and narration of the site. While the first project focuses on the question of ritual and myth and their expression in public space, the second presents a more tectonic approach, questions of vision and the meaning of an architectural detail. The third project takes yet another approach as it brings forth questions of political ideology and representation, of labor and materiality, and how those are represented in a domestic space.

*Fig. 6. The public review of student projects (left), and the exhibition of their work where a visitor with HMD exploring a scanned house through VR presentation.*

The first project, titled 'Stories of the Spring', focuses on the history and present of public rituals, myths, and conflicts around Lifta's water source, the historical origin of the settlement[13] In it, the audience is placed in three distinct situations in relation to the body of water, and is exposed to various happenings around it. The experience begins in one of the houses looking over the spring, in which the audience can both receive a perspective of the spring's location and presence in the village setting, and while exploring the house, the history of its residents and images of the 1948 evacuation. The second scene brings the audience to the spring itself, where figures of Hasidic men appear around the water, and the sound of children playing echoes in the background. At the same time, the work of a Palestinian female artist is presented in the vicinity, suggesting a tension between the two uses and meanings of the same site. The last scene brings the audience to the mouth of the spring, where a small canal channels the water towards the village. In it, the audience is exposed to the narration of a Palestinian refugee from Lifta, who explains the mythical significance of the site, while a 19th century etching of the spring appears within the point cloud model, giving the immersive experience of meeting an ephemeral character.

[13] For instance: Canaan, Tawfik. *Haunted Springs and Water Demons in Palestine*. Palestine Oriental Society, 1922.


*Fig. 7. Screen shots from 'Stories of the Spring' VR installation: One of Lifta's houses overlooking the spring, and a historical image depicting the evacuation of Palestinians from Lifta in 1948 (top); A point cloud scan of Lifta's spring, alongside an silhouette image of Ya'akub Oda, with audio of Oda's account of Palestinian life around the spring, and a 19th century representation of the spring (bottom);*

The second project, simply titled 'Openings', proposes to examine Lifta's history through the wide array of the apertures on the site, some of which are natural, some designed, some created by violence and war. The VR experience begins with a somewhat abstracted space, employing the notion of a cabinet of curiosities as instruments that "sought out objects which appeared to transgress the boundaries between nature and artifice," (Bowry, 2014) where the project offers a kind of aperture museum in which various scanned openings are arranged. While some apertures offer entrance to the original spaces in Lifta from which they were extracted by 3D scanning, others lead to archival texts and images related both to Lifta and to the notion of sight, photography and vision. Also, some of the openings connect beyond the limits of Lifta and provide the audience to look through them to related geographic locations, such as other Palestinian villages and cities, or sites of conflict and ruination throughout the world.[14]

[14] Problematic perhaps, one of the recurrent references when speaking to activists who are involved with Lifta is the case of Machu Picchu. For instance, the architect Gadi Iron, who is part of the Save Lifta Coalition, states that "We want to make a kind of Machu Picchu out of the village, Lifta is just as important." "Interview with Gadi Iron, Architect." https://www.zochrot.org/en/testimony/54959 (Accessed: 24 January 2020).


*Fig. 8. Screen shots from 'Openings' VR installation, showing a catalog of openings (left) from the site: windows, doors and holes, which function as portals to other places (right) in Lifta and beyond. Through the catalog of openings, the students devised a curatorial structure for the experience.*

The third project aims to narrate the story and history of Lifta by focusing on stone, the material from which the site, its architecture, and many of its traditions are created. Organized in three juxtaposed narratives, the project, titled 'Stones Sighing,' pulls strings and archives from various sources in order to expose the composition and decomposition of the site. The first narrative, which gives the installation its rhythmic structure, is the autobiographic poem, "Standing before the Ruins of El-Birwha," written by the Palestinian national poet Mahmoud Darwish. Narrated in three languages—the original Arabic, Hebrew and English—the poem accompanies the various scenes, inflicting them with the voice of Palestinian memory. The second narrative is that of the life-cycle of the stones themselves. Here, every scene takes place in a space that represents a different moment in the life of Lifta's stones. This silent material is animated through its historical procession, beginning with an excavated cave, continuing to one of Lifta's early houses, moving onto a more modern and recent residence, then a renovated house still occupied by an Israeli resident, and ending in a collapsed and punctured ruin. The last narrative of this project informs the stone's representational, ideological, daily and symbolic role. Focusing on the tradition of Palestinian masonry, the narrative exposes—through archival materials, historical texts and scholarship embedded and activated within the experience—the manner in which traditional methods, Palestinian labor, the very texture and chiseling of the stones themselves, became an instrument in the service of Israeli ideology and architectural design. Adopting the only vernacular tradition that could be found, modern Israeli architects employed the stones of Lifta (and of other villages), in the cultivation of a biblical image of Jerusalem, and in the design of contemporary, quasi-vernacular architectural works[15] (Nitzan-Shifta, 2017). The narrative ends with a heavily manipulated representation of the space in which this journey began; an emptied out and hollowed ghost frame of what was once Lifta's stones.

[15] Architectural historian Alona Nitzan-Shiftan makes note of the use of Palestinian masonry motifs, methods and styles in the design and conception of a post-1967 unified Jerusalem, meant to evoke a kind of biblical—rather than modern—image of the city and the state.

*Fig. 9. Screenshots from 'Stones Sighing' VR installation: One interior of the houses in Lifta in a state of disrepair (top) and another with two drawings from different sources and times, juxtaposing the same architecture typology (bottom). The archival findings of the relevant typology appear floating inside the 3D captured spaces.*

## Conclusion

International communities have recognized the significance of digital cultural heritage practice as expressed in a series of historic charters. The Venice Charter (1964) aimed to safeguard important physical sites through conservation and restoration efforts, while the UNESCO Paris Charter (2003) advocated protection and accessibility of digital content from books, artworks to monuments as information for all. More recently, the Seville Principles (2010) provided a framework for the creation of authentic visualization of cultural heritage.

In light of these, the underlying objective of heritage practices is to identify or create authentic content and to preserve it, either in physical or digital form, as "information for all". Therefore, the processes employed to warrant authenticity and appropriate methods for the preservation of sites and remains are key topics in these charters. Nevertheless, in order to animate these sites and remains, and to draw them out of their digital vaults, a digital cultural heritage practice needs to foster a means of delivering narratives that are associated and stem from the site and its history.

The case of Lifta not only demonstrates the technological capacity of contemporary digital tools for rapid onsite recordings, but rather complements those by critically reflecting on new ways in which digital heritage is created from these recordings, with narratives and curations embedded, for circulating and sharing the sense of various experiences of the place. Through the use of online collaboration and interactive presentations, the multiplicity of narrative histories and viewpoints becomes inherent to the understanding of the site as are its material remains. It produces a rich and diverse representation in its archival sources and one that, through community participation, holds the potential to grow and evolve through time. Such a representation can complement the outcome of traditional practice of cultural heritage project and bring a new value to a cultural heritage itself. At stake is not only a precise documentation of historical remains and evidence, but also the establishment of access for new publics to different forms of knowledge, and to multiple pasts.

With new means of documenting the site and its heritage raise new questions regarding the curation of materials. While it is becoming clear that digital narrative tools are persuasive narrative builders and may be used to build fictional worlds, it is ever more urgent to encourage its use for the curation of multifaceted narratives, which tell various stories of place and history, towards an open-source model for historiography and heritage.

## Acknowledgments:

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## Appendix: About the Lifta workshop

### Additional Collaborators

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Dr. Eli Cohen, Department of Bible, Archeology and Ancient Near East Studies, Ben Gurion University

Alon Havkin, Scan the City Project, Israel

### Student Participants:

Dalma Foldesi, Gabrielle Heffernan, Matthew Ledwidge, Jung In Seo, Radhika Singh, Cristina Solis, David White

### Itinerary (2019)

May 28–30: Preliminary training and research sessions at MIT

June 1–13: Fieldwork in Lifta, Jerusalem

- Field recording (photogrammetric captures, drone, Lidar, audio-video, 360 camera)
- Archaeologist lectures
- Onsite talk of former residents/settlers

- Meeting the local community group, Save Lifta

August 26–30: Project development at MIT design studio

September 28: Public review of student works

**VR Exhibition:**

September 24-October 4, Keller Gallery at MIT

*Digital Archeology, Virtual Narratives: The Case of Lifta*

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# In search for lost colours

## Challenge accepted.

Cristiana BARANDONI, National Archaeological Museum of Naples, Italy

***Keywords:*** *polychromy—3D modelling—archives—metadata*

**CHNT Reference:** Barandoni, Cristiana. 2021. In search for lost colours. Challenge accepted. Börner, Wolfgang; Kral-Börner, Christina, and Rohland, Hendrik (eds.), Monumental Computations: Digital Archaeology of Large Urban and Underground Infrastructures. Proceedings of the 24th International Conference on Cultural Heritage and New Technologies, held in Vienna, Austria, November 2019. Heidelberg: Propylaeum.
doi: 10.11588/propylaeum.747.

The National Archaeological Museum of Naples has adopted in its most recent history and post Cultural Ministry Reform (2015) a series of innovative strategies, whose physical and digital purpose is focusing on a conscious, inclusive, and responsible approach. The Museum's choices respond to the need for specific devices to be welcoming and satisfying, in today's globalized and dynamic society. Due to recent technological improvements museums are helped in this hard responsibility, by a wide range of possibilities they can choose from (Soren, 2009).

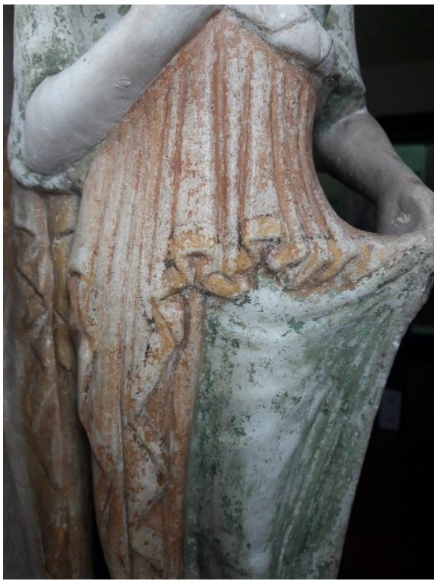

*Fig. 1. Lovatelli Venus (part.). Inv. 109608. National Archaeological Museum of Naples. (© Cristiana Barandoni)*

In this perspective, the National Museum decided to set a cultural policy that considers individual, collective, physical, and economic dimensions as priorities. Without this approach to culture and communication it would not have been possible to develop "MannInColours", a scientific project carried out in collaboration with the National Taiwan Normal University of Taipei. The project examines chromatic traces, sometimes imperceptible to the human eye but still existing, on sculptures, with the specific purpose to recover them visually; this will revolutionize the aesthetic perception to which these works have accustomed people for centuries (Jockey, 2014). From an educational and pedagogic point of view MannInColours attempts to convey a fundamental cognitive message for a sustainable, philologically correct approach to Greek and Roman statuary to the general public: a coloured vision (Fig. 1).

This approach seeks to comprehend the nature of a painted ancient world opposing the common misbelief generated at the end of the Eighteenth century; we are accustomed to black and white traditional approaches (sketches, drawings, vintage photo), which prioritize descriptions of our ordinary visual experience of colour. Given this costume, we need to argue that the ancient colour vision does not constitutively involve the ability to see colours, in a natural and categorically committed sense (Davies, 2018): we know we are promoting a coloured idea that plays a relevant role against a worldwide perception of the monochromic one. The error of perception becomes even more marked when we apply our idea of a black and white past to contexts: environment in which large conceptual complexities already exist, almost completely lacks the context (i.e., ancient statuary collections in museums). This is the real critical point: on the one hand, scientific investigations tell us about a powerfully shaded ancient world, appearing on almost every surface, rarely in subtle tones (Fejfer, 2008; Ball, 2001); on the other, our cemented view of the classical period impulses perception to see a pale and white *past*. No surprises if any attempt to return the original appearance to archaeological artefacts in multiple forms (both materially painting copies of originals and virtually with augmented reality) is met with disbelief from the public (Jewell, 2013). How can museums exhibitions help to respect original colour appearance? What can they do to enhance awareness of colour? It is not only about a popular imagination of colour vision but it is how can they help publics "seeing the colours" (Chirimuuta and Kingdom, 2015), which means also shape, depth and motion?

Colours in ancient times were not only superfluous decorative *rêverie* but played *a salient role in the classification of precious objects* […] *the "value" of a colour* to which add material, texture, and shape, *was connected to iconography* (Brecoulaki, 2014). Colours were not casually selected since they mirrored social and financial status of the client whether he/she used his/her finances for public donations or for private wealth. For these reasons, it is essential to rethink the world of colour not only as a decorative accessory but as a means of communicating one's social and cultural status. In ancient times colours were semiotic markers to mediate a socially and culturally constructed visual language (Skovmøller, 2015). The polychrome treatment enhanced the value of the sculpture (Blume, 2010).

With this awareness, the project was developed taking some aspects in great consideration; the only possible conclusion was planning varied actions to spread the right message, prioritizing principles, and missing connections, restoring original lacking context and colours. The approach to the study of ancient polychromy cannot ignore this: in every dissemination action carried out by the National Museum the relationship between object and message addressed to public is a huge and pressing priority. Thus far the *experience* aims to mend this tear by combining the most modern virtual technologies offered by the NTPU to understand the meanings of the codes underlying the choice of one colour rather than another. Digital media, whose use is becoming increasingly widespread in museum communication and teaching practices, can be considered a useful experimentation, suitable for this specific purpose. In 2017 a congress in Bordeaux[1] upraised the problem of how and why it is worth the reconstruction of ancient polychromy in terms of research and dissemination: these urgencies appear more and more frequently in this field. It certainly entails awareness by scholars who now also take into consideration the “social” aspect of the museum, guaranteeing access to their research also for a public of non-experts; in general, it means that researches in this field should embrace more than one single audience, spreading knowledge even among non-scientists.

No one complains (actually) about the use of digital media or virtual reality to help in understanding, but it is missing is the method to employ it to reproduce ancient colours: a method has still to be identified (if existing). There is no questioning about physical reproduction since a lot of virtuous examples inhabit some of the most important museums in the world. At Ny Carlsberg for example, alongside original sculptures, on the surface of which colours are almost imperceptible to an untrained eye, plaster copies have been placed, reproducing (or copying?) the originals quite faithfully. We are still dealing with copies and modern colours applied on different surfaces (marble against plaster), not to mention the myriad of brushes. And the nuances? Are we sure that colours completely covered the surfaces, or is a close link with painting and its glazes more plausible? If these are just some of the key issues in the physical reproduction of colour, of a hugely different nature and complexity are those that concern their reproduction using digital media. But it worth a try. In addition to a complex choice, it is also a question of ethics and responsibility towards visitors, to whom these experimentations are addressed.

This paper however provides only a fragment of the more general question on the reoccurrence of colour in the context of the artistic productions of the ancient world. Statuary, indeed, should be examined in relation to architecture, for a plenary vision, to understanding sculpture’s positioning related to environment. Obviously, lacking a wide-ranging vision, we can only aspire to a partial half-finished reconstruction; sculptures were only one of the tools through which propaganda was made: meanings, ambitions, socio-cultural and political messages of the clients were communicated through multiple arts and crafts, so it was through architecture. Starting from this assumption, to try and reconstruct the original, coloured appearance, it is necessary that a method is established which takes into consideration not only the material object but the context within it was sited.

Two of the numerous cases to be examined in this perspective, are the Lovatelli and Bikini Venuses, for both of which we can reconstruct many phases of the ancient excavations leading to their discoveries; rebuilding context is enabled by a discreet presence of archival documents, allowing philological study to be transformed into exhibitions as staging point of a restoration *experience*. Circumventing this step would mean museums conferring to public false notions and vision of the past, especially considering their need to educate to a philologically and historically truthful context; the reconstruction (if possible) of original archaeological context as a *conditio sine qua non* for proper training and communication strategies is the only way for people visiting museums to understand what meant to paint sculptures and architecture.

[1] “Restituer les couleurs: Le rôle de la restitution dans les recherches sur la polychromie en sculpture, architecture et peinture murale” (Bordeaux, 29 novembre-1er décembre 2017)

*a* *b*

*Fig. 2. a) Limestone sculpture of Horus from Roman Egypt. EA51100 (Photo © The Trustees of the British Museum); b) A colour reconstruction based on pigment analysis suggests how the statue originally may have looked. (Photo © The Trustees of the British Museum). Source: https://blog.britishmuseum.org/pigment-and-power-dressing-in-roman-egypt/*

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# Conservation of Cultural Heritage and Documentation Techniques

## Bursa Forestry Museum (Saatçi Ali Pavilion) Conservation Problems and Suggetions

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***Keywords:*** *Bursa Forestry Museum—Bursa Pavilions—Documentation—Restoration—Conservation*

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## Prologue

Located in Çekirge District of Bursa Province, the structure, which functions as the Bursa Forestry Museum is affiliated to the Ministry of Agriculture and Forestry, was built in the 19th century and is a pavilion structure with other examples in its immediate vicinity. Besides the masonry basement floor and two floors built with timber-framed construction technique, the building also has a wooden annex, a wooden gazebo and a recently added lodging building. The structure has been used in different functions in its historical process and after the allocation to the Ministry of Forestry in the middle of the 20th century and different functions related to forestry, it has reached the present day with the function of "Forestry Museum" as it has been the one and only forestry museum in Turkey. During this process, it was observed that there were damages in the structure due to natural causes as well as human factors, and it was found that the structure needed protection.

### The Aim of the Study

"Saatçi Ali Pavilion", which is one of the many mansions built in Çekirge region in the middle of the 19th century, during the last periods of the Ottoman Empire, is one of the few period structures that have survived to the present day (Özdemir, 2007). Within the scope of the study, historical development of Bursa City was examined and historical mansions in Bursa and Çekirge District were investigated. In 2019, Survey-Restitution-Restoration projects were prepared by Bursa Regional Directorate of Forestry and by U2 Architecture Office. The building survey was taken by laser scanning, photogrammetry and traditional methods (tape measure, spirit level, profile comb, etc.). These projects were examined and the conservation problems were identified with the help of these documents. Suggestions have been developed to solve these problems within the framework of contemporary restoration theory.

## Historical Development

Çekirge District covers the 1st Murad Hüdavendigar Complex and its environs, which are located in the westernmost part of the Old City of Bursa, and its settlements in the east and west directions. It has been an important health and summer vocation district with its underground hot water resources since the Byzantine period (Çinici, 2017). Thanks to the volcanic mountain Uludağ (Olympos), the hot water springs in this region were observed to be curative over time and settlements were made for the use of these springs. The oldest spa known from these settlements is the thermal bath built by the Roman Emperor Trajanus. Later "The Old Bath" was built by the Byzantine Emperor Justinian I. (527–565) (Özdemir, 2007). It has been a resort and cure-health center since the 6th century due to its natural areas and hot water springs.

## Architectural Description of the Building

Bursa Forestry Museum Building, located in Çekirge Neighborhood of Osmangazi District of Bursa Province, has two floors consisting of brick basement floor and brick filled walls between timber-framed structure. In the same parcel, the timber-framed annex structure and the wooden gazebo structure were built during the first period of the mansion, and the reinforced concrete housing structures were built in the following periods (Yalman, 2011). The building was named after Saatçi Ali Efendi, who built the building, and was used as a residence until 1936. Between 1936 and 1949, it served as the Secondary School of Forestry, which trained engineer assistants. After serving in the Regional Directorate of Forestry until 1983, it served as the state department of this institution. Since March 29, 1989 also operates as Turkey's first Forestry Museum (Özdemir, 2007).

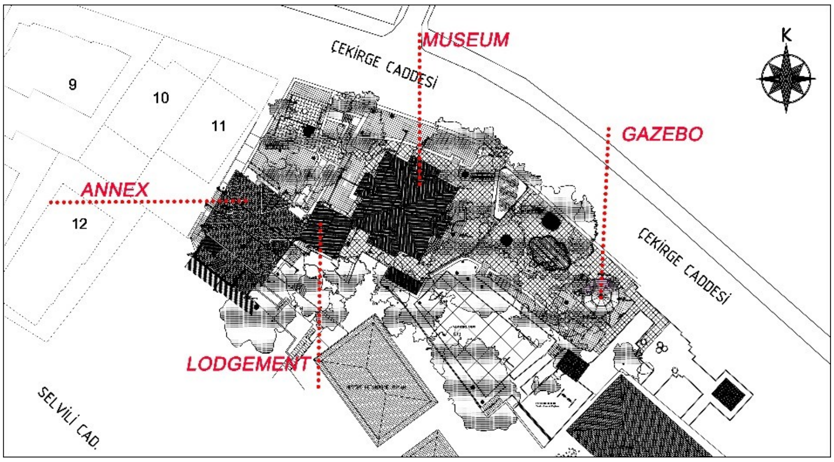


*Fig. 1. Bursa Forestry Museum Layout Plan, Bursa, Turkey (© U2 Architecture Office Archive).*

The Forestry Museum building can be shown as an example of the plan type with a middle hall. Transitions to the rooms are made from this hall. The structure is rectangular in the east and west direction. The buildings façades are all open. It was observed that the tile cover of the timber-framed roof of the building was recently changed.

## Conservation Problems

There was no structural damage and serious damage. There are paint spills and joint opening in the exterior cladding. Wooden windows and doors have paint spills. Time-related wear and moisture have been observed on the floor beams in the basement ceiling. There are many layers of paint on the walls of the building and they are poured from place to place. Gypsum plaster made on ornaments on the wall caused great damage to these embellishments. The ceiling coverings in the structure and the decorations made in the painting technique on the canvas are original and damages such as contamination and rupture have been observed to a great extent. On the first floor there are unauthentic wooden elements on the walls and ceilings of the rooms in the southeast. It is considered that roof carriers generally do not have structural damages. Corrosion and buckling were observed in the zinc coating on the windowsills of the building facade. Zinc rain downpipes of the structure have been replaced by unauthentic material in some places.

*Fig. 2. Southeastern Façade of the Building and the Main Entrance, Bursa, Turkey (© Oğuz Yeke).*

**Studies and Conservation Suggestions**

After examining the building survey, deteriorations affecting the structure, unauthentic additions and situations that need to be intervened were identified and protection recommendations were made. Repairs in line with these recommendations should be done in a way that will cause minimal damage to the original tissue, attention should be paid to the construction technique and materials, and restoration application should be done without changing the internal order of the structure (Ahunbay, 2004). The existing wooden elements in the structure should be painted with paint scraps, and if there are rotting parts, they should be renewed in their original details and materials. The unauthentic coating on the roof should be removed and the necessary reinforcements should be applied. Necessary arrangements should be made in the creeks and ridge on the roof and the existing roof tiles should be replaced with the traditional Spanish tiles. The wooden shutters on the guillotine windows, which were determined from the old photographs, should be rebuilt with original detail and material and replaced. The original wooden flooring should be repaired. The original ceilings in all spaces should be scraped away from paint and decaying and repairing elements should be identified. After the inspection, protective natural wood varnish should be applied and re-painted and replaced.

a b c

*Fig. 3. Forestry Museum inner walls and ceiling ornaments. a) Stair Hall; b) Ornament in Stair Hall Wall; c) Room Ceiling Detail (© Oğuz Yeke).*

Stone imitation pavements surrounding the facade at the level of the basement of the building should be removed and covered with plaster as determined from the old photographs. After the decaying and needing parts of the zinc surfaces on the upper cornice of the facade and windowsills and the wooden parts that are underneath are determined, they should be treated with protective varnish. The existing lodging structure will be preserved by cleaning the arched chimney from the original fire brick located in the basement. During the survey, the ornaments on the wall, traces of which were found during research scraps, should be designed and renewed during the application.

## Conclusion

Suggestions developed for the preservation and restoration of the building, which reflects a period of Bursa city architecture, should be carried out in a way that the restoration applications to be made in the future will be integrated with the environment of the building and will not disturb the original design and details. It should be remembered that the museum, which is the present function of the building, is open to the public of all ages, which is the most suitable function for the promotion and survival of the building and the works related to the forestry activity exhibited in it.

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## Session:
## Deploying Geographic Information System (GIS) and Remote Sensing (RS) in heritage conservation, theory and practice

Reza SHARIFI | Alireza IBRAHIMI | Marco BLOCK-BERLITZ

# Deploying Geographic Information System (GIS) and Remote Sensing (RS) in heritage conservation, theory and practice

Chairs:
Reza SHARIFI, Brandenburg University of Technology, Cottbus-Senftenberg, Germany
Alireza IBRAHIMI, Avicenna University, Kabul, Afghanistan
Marco BLOCK-BERLITZ, HTW Dresden, Germany

***Keywords**: Geographic Information System (GIS)—heritage conservation—decision making*

Heritage conservation and archaeology are interdisciplinary subjects; in these fields utilising the spatial data from historic sites and objects are playing a pivotal role. For heritage managers geodata are an essential source of information, which leads to better decision making. In this field, various techniques and methods related to Geographic Information System (GIS) and Remote Sensing are advancing in a swift-paced. Therefore, the heritage practitioners need to handle with this new technology.

Theoretically, we can divide GIS implication in the field of conservation into different phases: a) Gathering data b) Data Input and Verification c) Data Storage and Database Management d) Data output and presentation and e) Data transformation, analysis, and modelling. In all these fields heritage conservation can benefit, in terms of cost-benefit and task quality. GIS in the field of heritage needs to cope with other new and advanced topic such as Cloud computing, artificial intelligence and so on.

Among all the issues, in our session, we invited researchers to contribute to the frame of the below areas:

- Using GIS to integrate the spatial data, produced by the survey, historical maps, etc., from different sources attributed to the cultural heritage;
- Utilising remote sensing methods such as Satellite Imagery and Arial photography in heritage analysis, and monitoring;
- New GIS methods in heritage documentation  for sharing, publishing and storing;
- Using internet-based GIS platform and techniques such as Spatial Data Infrastructure (SDI), WebGIS, mobile GIS;
- Role of GIS in decision making, especially on sensitive cases like destruction during excavation or damages due to illegal actions or conflict.

# Seismic Risk Assessment. The Case of the Exhibition “Di Tutti i Colori” in Montelupo Fiorentino, Italy

## From Theory to Real: Conception, Project, and Realization of a Temporary Exhibition

Giada CERRI, DIDA – Department of architecture, University of Florence, Italy

**Abstract:** The paper is part of a work-in-progress research on earthquake damage mitigation for museum collections. It is part of the research multidisciplinary project *RESIMUS – Resilience Museums* developed by a group of researchers of DIDA – Department of Architecture of the University of Florence. Although the large acknowledgment on seismic risks, a shared culture on the protection of museum collections is still missing. The contribution focuses on some museographical aspects, precisely on the design of a temporary exhibition. It illustrates the application of the RESIMUS approach to the temporary exhibition di *Tutti i Colori. Racconti di ceramica a Montelupo, dalla “fabbrica di Firenze” all'industria e al design (*on show in Montelupo Fiorentino – Italy from March to September of 2019). The paper illustrates the preparatory phases of the exhibition, the strengths and weaknesses of the event, the adopted methodologies, and the outcomes. One of the research goals was to narrow the gap between academic theory and everyday museum practice. This exhibition represented the opportunity to raise awareness about the importance of the seismic risk assessment in temporary exhibitions.

***Keywords:*** *Temporary exhibition—Seismic vulnerability—Ceramics—Museum—Best practice*

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## 1. Introduction

Earthquakes represent a threat to cultural heritage. Although a general awareness about the importance of anti-seismic measures is raising, this mostly concerns buildings and constructions. After an earthquake, the registered extensive damages to the movable cultural heritage triggered a reflection. Both academic and professional milieu questioned the possible applicable solutions to protect the content of museums, galleries, and churches. There is a wide body of literature about the seismic risk assessment of movable cultural heritage. This interests mostly big artifacts and the dynamic behavior of the objects. The Getty Museum of Los Angeles, USA, was a pioneer regarding the analyses of the risks for museum collections (Podany, 1991). Academic studies pursued a series of tests to forecast the scenarios of danger and therefore identify the best suitable solutions to avoid damages (Berto, 2012; De Canio, 2012; Liberatore, 2000; Ciampoli, 1992; Agbabian, 1990). Some museums, after experiencing uncountable losses, started applying anti-seismic devices to some objects of their collections (Archaeological Museum of Olympia, Greece, Kobe Museum, Japan, Getty Museums, Los Angeles, USA) or constructing new anti-seismic museum structures (Christchurch Art Gallery Te Pan o Waiwhetu, New Zealand; MUNDA – Museo Nazionale d'Abruzzo, Italy). Although the large acknowledgment of the risks caused by a seism, a shared culture on protecting museum collections is still missing and the gap between academic literature and practice is wide.

The paper presents part of a work-in-progress research on earthquake damage mitigation for museum collections. It focuses on some museographical aspects, precisely on the design of temporary exhibitions. The next section introduces the research project RESIMUS, RESIlience MUSeums, of DiDA – Department of Architecture of the University of Florence. The third section focuses on the existing protocols and measures about the seismic assessment of the movable museum collections, and the following one presents the application of the RESIMUS method to an actual case study: the temporary exhibition *di Tutti I Colori*. The article concludes with general remarks, highlighting the necessity of considering the application of anti-seismic measures inside temporary exhibition design as a good practice. In particular, it highlights the possibility of integrating both coherent museographical design and anti-seismic devices. The result is the progressive improvement of the museum display settings.

## 2. Seismic Safety of Exhibitions: Documents, Guidelines, and Protocols

Preservation, conservation, and enhancement are capital keywords in the museum field. International committees, museums, and cultural institutions collaborate to delineate common guidelines, standards, and shared protocols for protecting museums and museum collections from various risks. The text edited in 1993 by ICOM and ICMS, Museum Security and Protection, A handbook for cultural heritage institutions, was intended to be a general textbook with international standards and basic security procedures. Later, other texts have been released. One is *Running a Museum: A Practical Handbook* (2005) by ICOM, a compact manual born to be a reference book to those working in museums in Iraq. Given the universal interest of the topic, this has been customized to be a basic book dedicated to those working in museums. Other texts came along (Jalla, 2015), they all share the necessity of setting common parameters and procedures to protect, preserve, and enhance the cultural goods. In Italy, the text elaborated jointly by MIBACT, ICOM, and Carabinieri nucleo tutela patrimonio culturale (2015) represents the most updated document in this field. Although dedicated to the protection against theft, vandalism, terrorism, smuggler, etc., it proposes useful measures and suggestions on museum risk assessment. These documents are precious and necessary. Unfortunately, none of them dedicates to the seismic hazard. ICOM and UNESCO devote documents to the emergency and to the recovery after earthquakes, but not about prevention (Sendai, 2015; ICOMOS, 2014; HFA, 2013; 2007). Up to now, common sense, practice, and high expertise of the museum staff are the most effective preventive measures against earthquakes.

In practice, some museums have applied anti-seismic measures to some of their pieces (De Canio, 2012; Cigada, 2016). Unfortunately, these expensive operations commonly occur after the damages. Rarely, they are preventive acts (the Milanese case of the Pietà Rondanini is an exception). These interventions usually concern big or iconic artifacts, such as sculptures, and the application of specific technologies, like isolation platforms (McKenzie, 2007). The lack of specific norms and prescriptions dedicated to the preservation of museum collections in case of earthquakes involves museums at both international and national levels. Norms and actions direct usually to the structure of the building (NTC, 2008) without considering the contents. The Getty Museums first tested some preventive measures to a series of objects of medium-little dimensions, becoming a pioneer[1] in the museum panorama (Podany, 1991). In the volume *When Galleries Shake* (2017), Podany presents some examples of safety solutions applied to objects on show: clips to hold vases to the cases, shaping mounts, special holders, weights inside the vases. He showed that little gestures, and limited money, sometime might avoid uncountable damages. The measures of prevention and protection of museum objects are essential to both permanent and temporary exhibitions. According to Podany (2017), in the case of an earthquake, temporary exhibitions are the most exposed setups. Besides, in certain geographical areas shakings of low-medium intensity might be frequent. They rarely affect the structure but can be dangerous to collections, causing extensive damages to objects and people.

The lack of norms also affects the temporary exhibitions. In organizing it, both the lender and the host venue have to follow some procedures and restrictive protocols (London agreement – IEO, 2002). Among the several documents, the facility report comprises a form describing the spaces of the hosting institution (MIBAC, 2002). Each loaned object is accompanied by an ID form. This document lists the requested safety and conservation measures of each traveling piece, for example: alarmed case, specific hygrometric environment, temperature of the light, etc. (ICOM, 2014). If the hosting museum satisfies all the mandatory conditions, the loaning institutions give his clearance to proceed. The anti-seismic devices are not requested yet.

## 3. Seismic Risk: the RESIMUS Research Project

RESIMUS (Resilience Museums) is a multidisciplinary ongoing research developed by scholars at DIDA – Department of Architecture of the University of Florence. It focuses on the preservation of the cultural heritage and on raising awareness about the seismic hazard for museum collections and museums (Viti, 2018). The academic research team is composed by academics coming from different fields: museography and architectural composition, structural engineering, history of architecture, survey and new technologies applied to architecture. The team collaborates with professionals (geologists, restorers, museum curators, etc.) and museum institutions (e.g., National Museum of Bargello, Florence – Italy; National Archaeological Museum Gaio Cilnio Mecenate, Arezzo – Italy).

The main RESIMUS research project's goals are: preserving the movable cultural heritage, raising awareness about the seismic hazard for museum collections and museums, spreading the culture of seismic prevention of museum collections among the cultural institutions. To do so, the team provides innovative responses to vulnerability, understanding the fragilities of museum collections and exhibitions and proposing solutions that integrate both coherent museographical design and anti-seismic devices (Cerri, 2019). The first steps are the analysis and the rating of the collections. The data are obtained by filling in the RESIMUS form (a standard form customized by the RESIMUS team) and both experts and non-experts can complete it. This records the current situation of: museum building, one of the rooms, internal setting of that room, the typologies of the showcases, and

[1]It is worth mentioning that the Getty Foundation and Research Center are partners to several museum and institution around the world located in other seismic lands

the objects. The analyzed results give the vulnerability rating of: objects, showcases, and rooms. After a phase of consultations (between the research group and the members of the museum team), the final goal is the design project (alternative layout or improvement of the existing setup). The challenge is elaborating projects that guarantee both safety and responsive behavior in case of a seismic event. Such operation increases the awareness of the museum about seismic prevention. The group tested this approach at the National Museum of Bargello, Florence (Cerri, 2019; Viti, 2018).

## 4. The Case Study *Di Tutti i Colori*

The design of the exhibition *Di Tutti i Colori. Racconti di ceramica a Montelupo, dalla "fabbrica di Firenze" all'industria e al design* was the occasion to apply the RESIMUS approach to temporary exhibitions and to test it. Before, the RESIMUS team used it in two museums (Florence and Arezzo) and on permanent exhibitions and on single artifacts (Cerri, 2019; Tanganelli, 2018; Viti, 2018).

### About the exhibition: general information

The city of Montelupo Fiorentino is part of the metropolitan territory of Florence (Città Metropolitana di Firenze). Montelupo is historically important for the production of ceramics. The city gained its fortune thanks to the Medici's dynasty that traded its ceramics around Europe and the Americas. After periods of low production, the place acquired new prosperity in the aftermath of the Second World War, when some kilns started collaborating with artists and designers. Today, despite of the crisis of the sector, Montelupo is one of the most important Italian ceramic districts. The Montelupo Museum Foundation manages the museums, promotes the local production, and conserves the historical collections. *Di Tutti i Colori* opened from March 6th to July 28th, 2019 and was set up in the *Palazzo Podestarile* (Podestà's Palace). The Palace is the hosting venue for temporary exhibitions and special projects curated by the foundation. This historical building used to be, in order, a civic palace (Podestà's residence and then Municipal House) and the prior location of the Ceramic Museums. The building articulates on four floors, only two are equipped for exhibitions (ground and first floor). The follow-up of the exhibition dedicated to the Renaissance period was organized within the current Ceramic Museum.

The exhibition told the history of the local ceramics from the 13th Century to the current days (Mandolesi and Vignozzi, 2019). More than 120 ceramic objects narrated: the rise and fall of this ceramic district, the innovations and the new techniques, and the recent design experiences. Organized chronologically, the exhibition used the colors as a narrative thread. The ground floor hosted the ceramics from the 13th to the 17th Century, the first floor that from the 18th Century to nowadays, and a special section was dedicated to the ceramics for the table.

The visit began with an immersive space. Sounds, lights, and images transported the visitor in a suspended atmosphere, calling back the protagonists of the exhibition: colors, ceramics, and the city of Montelupo. The colors represented a distinguished element of this specific ceramics. The so-called traditional exhibition started after the introductory rooms. The exhibit design was intentionally simple. The concept of the exhibition was to present the ceramics in a suspended environment where the bright colors of the objects stood out on the neutral tones of the background. Light semitransparent fabrics hanging from the ceiling were the leitmotiv of the design. The fabrics characterized the spaces and served as communicative supports.

### The Design of the Exhibition

In general, the production of a temporary exhibition involves many fields and knowledge. The success of the event is given by the combination of the synergic work of many people with unique backgrounds and roles[2]. The design of this exhibition was conducted as a whole. The solution was a combination of: analysis of the site and of the objects on show, coherent museographical approach, and adoption of safety measures. The budget was low and, since the beginning, the designed solution was intended to be: simple, economic, and seismically safe. Thanks to the studies conducted by the RESIMUS team (numerical and virtual models, testing labs, review of the literature), the range of the available safety solutions was quite clear. The difficulty of the operation was to combine such solutions, the design idea, and the materials already possessed by the museum. As anticipated, the concept of the exhibition design was to stress the narrative power of the ceramics (color, shape, decoration). The outcome was the combination of three elements: a flat platform, on which bases, and cases were arranged; the semitransparent hanging fabrics, to articulate the space and as a support of all the accompanying texts; the showcases. This represented a sort of basic module of the exhibition.

In exhibition design, the digital instruments are powerful resources. Here, they were used in two different phases: 1) management of the exhibition 2) immersive exhibition. First, the construction of the exhibition has been discussed upon a 3D model. The virtual model allowed the curators to visualize the work in progress design and to agree on the final result. The possibility of discussing on both two-dimensional and three-dimensional visualizations eased the dialogue within the group. The model allowed the general evolution control of the project, characterized by a high number of the pieces. The management of the pieces was handled with a relational database (FileMaker). Instead of polished renderings or sophisticated models, a light and easy-to-change model was used: SketchUP. Instead of having photorealistic renderings, the visualization has been realized through digital collages. Second, the immersive spaces were accomplished in collaboration with the studio Unità C1 Visual Environment. An animated ribbon, flowing on two walls, and a virtual decorative plate characterized the first room. The technology was simple: two projectors, music, and one digital video. In the second room, the projections directed on three walls, one of which was a mirror. The result was a digital elaboration and composition of pictures and sounds. Such immersive multi-sensory space worked as an introduction to the exhibition. Due to the typology of the exhibition, there was no need for advanced numerical digital calculations as applied in some RESIMUS research (Tanganelli, 2018, Viti, 2018).

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[2] The realization process goes under five main steps: I) Feasibility (Idea, Feasibility - cost, resources, etc., Purpose Statement); II) Preliminary Design (Assembling the Players, Communication Goals, Rough Schedule and Budget, Research/Front-end Evaluation; Storyline/Conceptual Design/Formative Evaluation, Design the conceptual design or layout of the exhibit area, Describe the look and feel of the exhibit); III) Detailed Design (Script/Final Design/Formative Evaluation, Cost Estimating and Design Revisions, Communication design); IV) Production Planning (Final Production Schedule and Budget, Construction and Specification Documents, Promotion of the event); V) Production (Fabrication and Installation, Opening, Maintenance, Summative Evaluation, Exhibit Redesign/Adjustments, Disassembling). See: Smithsonian Institution, THE MAKING OF EXHIBITIONS, 2002 Capital Heritage Connexion https://www.capitalheritage.ca/plan-design-exhibition/; Eventually, there should be a sixth phase in the case the exhibition foresees a follow up or animation during the time of opening.

## The Seismic Risk Assessment of the Exhibition

The challenge of the design operation was foreseeing a low seismic risk assessment of the exhibition by applying anti-seismic devices. As for the general design, the anti-seismic devices were included in the initial budget. The goal was to gain the greatest of the result with the least expenditure. From a conservatory point of view, ceramics is a simple material: it does not suffer from high or low temperature, light exposition, and specific hygrometric conditions. The only threat is the dust. The risk assessment for the ceramic exhibition concerns: theft, accidental hazard, and natural disaster. The first two risks depend on people and are solved by applying standard procedures (described in the procedure of loans). The natural disasters are rare, not predictable, and rarely considered. The adopted solutions followed Podany's prescriptions and suggestions and derived from the RESIMUS studies. About the seismic risk assessment, the evaluation of the risks depended on: geometrical configurations, typology of the objects, and goals (Tanganelli, 2018). In this exhibition, specialized calculus and advanced models were ineffective. Thus, the expeditious approach was identified as the best option (low cost and effective). The prediction of the risks was expected using the RESIMUS form. Instead of having self-standing bases, the project foresaw the fixation of them on large platforms. The platform worked as a stabilizer, preventing the movements of sliding, rocking, and overturning. Such system worked as one structure.

The white platform had the functions of: absorbing the vibration in case of an earthquake, working like a distress pillow; being a braking distance, avoiding the necessity of other physical solutions (barriers); being a sort of continuous white path. The platforms had variable extensions (depending on: the site specific location, the typology of the room, and the specific objects on show). The showcases, already possessed by the museum, were placed on top of the platforms. To maintain an adequate level of protection, the adopted solution was to fix the cases to the platform, avoiding or mitigating the risk of rocking, overturning, and sliding. Some of them were open, others locked by a transparent case. Although plates, jugs, mugs, vases are light objects, they still need to be secured to the bases. Special fixing and removable wax, sacks filled by sand, and specific mounts were used. As said, little but effective actions would prevent significant damages. The sum of all these actions diminished the risk level of the exhibition.

## The realization of the exhibition

Unfortunately, some events modified the planning and the project. In particular, a budget review and some mistakes in general management caused major delays. Running close to the opening, a series of cuts and simplification of the projects were made. Although unpleasant, it is a recurrent situation in these kinds of events. The effort is finding doable compromises. The consequence of the budget cut was the reduction of the expenditure, like carpentry, so the platforms became flat panels. A series of delays and the move up of the press tour by four days before the opening caused the anticipation of the delivery of some of the loans. When the first objects arrived, the exhibition works were at the end but still ongoing. Once a loan is placed and locked no one can touch or move it (nor it or and its case). Thus, there was no time to fix all the showcases and the bases at the panels.

In spite of everything, the exhibition opened in the right term, received good critics and reviews. It was visited by a discreet amount of people and both the Foundation and the Municipality (the organizers) were satisfied with the results. Unfortunately, safety measures were not fully applied. This was a lost occasion of realizing the first complete anti-seismic temporary exhibition. Without preventive devices, the exhibition had not a low level of risk.

## 5. Conclusion

Delays, complications, obstacles, and errors might occur during the setting up of an exhibition. Usually, these are solved applying contingency plans. Unfortunately, the elements not prescribed by law and perceived as superficial might be cut off to save money or to hurry up. Such choices complicate the process of assessing the risk level of the setups. Therefore it is important to have codified and shared guidelines about the protection of the collections, also from earthquakes.

The case of the exhibition is useful for the RESIMUS project for several reasons: it is the first attempted test of the RESIMUS approach on a temporary exhibition; it proposed and tested simple and low-cost solutions, which, in theory, every museum can adopt; it was the occasion for testing the different settings with and without the safety measures; the RESIMUS has been used also as a risk assessment form.

Although the digital technologies were not used in a innovative way, the novelties are the approach and the scope of the project. The exhibition contributed in raising awareness about the seismic hazard for museum collections. Although the application of the preventive measures did not completely succeed, the exhibition was the occasion to start defining a selection of best practices to share among museum institutions and international museum bodies (ICOM, UNESCO, etc.). One of the major goals of the RESIMUS research is to contribute to filling the gap in the museum policy framework (e.g. safety guidelines, emergency plans, etc.) in both national and international contexts. The case of the exhibition di Tutti I Colori represented an important unique field of experimentation.

Quoting Podany (2017), “we cannot yet predict or control the inevitable earthquakes, but the damages resulting from their forces can be reduced. We should begin.”

## Figures

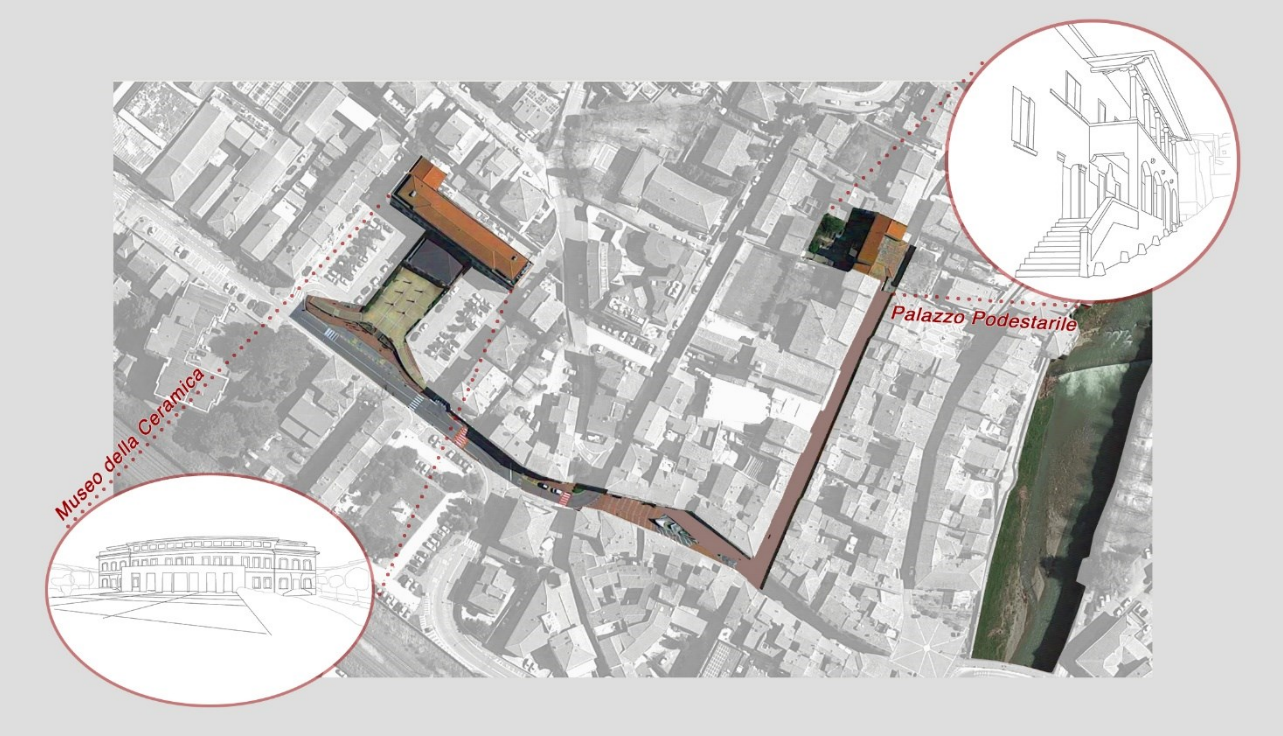


*Fig. 1. Venues of the exhibition (© Giada Cerri)*


*Fig. 2. Concept of the exhibition design (© Giada Cerri)*

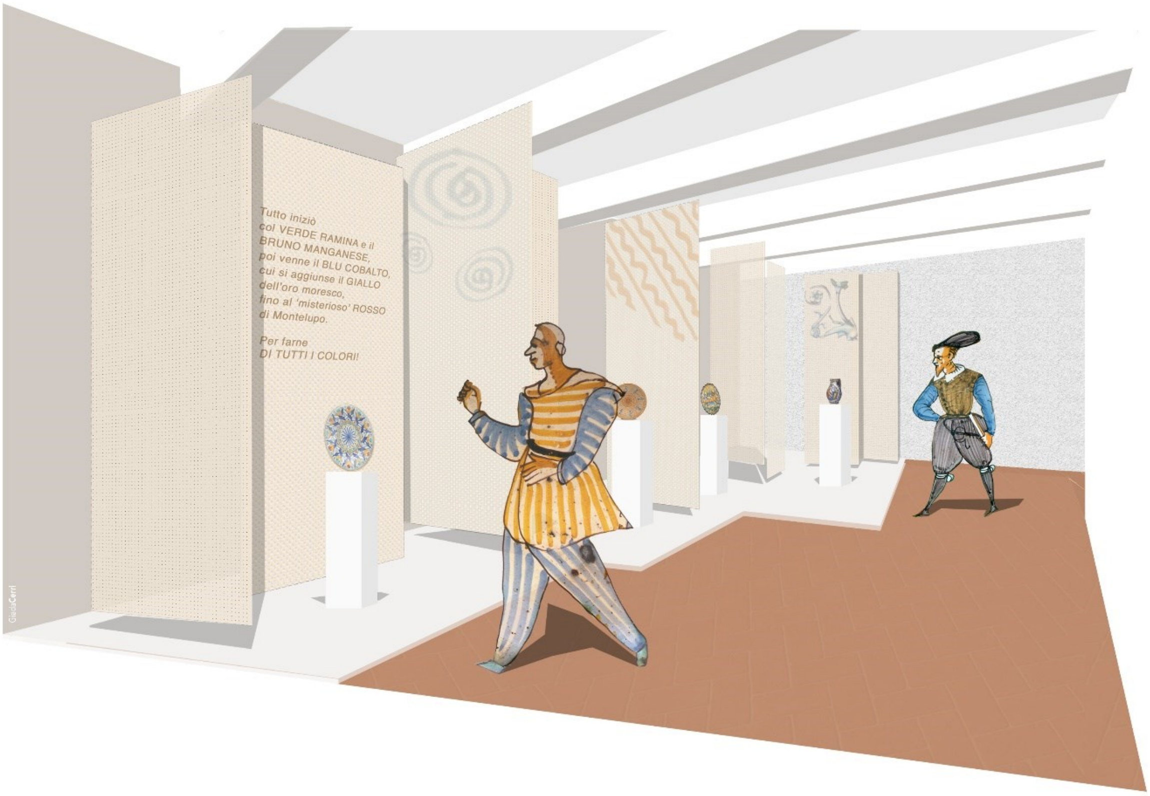


*Fig. 3. Maquette of the exhibition design project (© Giada Cerri)*


*Fig. 4. The exhibition, ground floor (© Anna Positano)*

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# From the Hypogeum Culture to Cities of the Future: Ars Excavandi

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**Abstract:** The Ars Excavandi international exhibition, created by ETT S.p.A. (International Creative and Digital Industry) for the Matera 2019 Foundation and curated by architect Pietro Laureano (a UNESCO consultant), opened the celebrations in Matera as it became European Capital of Culture 2019. The exhibition highlights the importance of underground art culture and investigates art and excavation practices that brought about architecture, civilisation and rocky settings over the centuries. The visit, linking the National Archaeological Museum "Domenico Ridola" and the hypogea of Palazzo Lanfranchi in Matera, takes visitors on a journey ranging from the Palaeolithic to the present, stimulating them to consider how topical the cave world is when designing future models of human progress. The multimedia path has been created in order to follow a chronological order, with references at the bottom of the timeline. Continuous timeless analogies are present on the walls with art, craft, traditions, folklore, music and rituals. The exhibition virtually recreates a space-time tunnel going from Matera to the cities of Petra and Jericho, from the first excavations to a model for future bio-architecture. Visitors, through the use of sounds and scents, projections, backlit walls, videos, and a gaming station, will be catapulted on a journey taking in the past and the present, making all past civilisations seem modern.

***Keywords:*** *Multimedia experience—Hypogeum—Virtual reality—Videoprojection—Gaming*

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## Introduction

The Ars Excavandi international exhibition, curated by architect Pietro Laureano who drew up the dossier to add the *Sassi* and the *Murgia materana* into the World Heritage List, is created by ETT S.p.A. for the Matera 2019 Foundation in collaboration with the Polo Museale della Basilicata (Museum Hub of Basilicata region). The exhibition investigates art and excavation techniques that gave birth to architecture, civilization, and rocky settings over the centuries. It retraces, from a contemporary perspective, the hypogeum art and culture history from the first usage of natural hollows and rock engravings to the realization of caves, settlements, monuments, and waterworks based on excavation. The visiting path, divided between the "Domenico Ridola" Museum and the Palazzo Lanfranchi hypogea, drives visitors into a journey form Palaeolithic to the present, showing how topical the cave world is when designing future models of human progress.

The visiting path is developed in five stages characterized by the elements Air, Fire, Eros, Water, Earth marked by the colors Yellow, Red, Ultraviolet, Blue, Green and by a series of sounds and scents. It takes place chronologically with references in low to the timeline, and on the walls there are continuous timeless analogies with art, craftsmanship, traditions, folklore, music, rites. The conceptual paradigm is that all ages are contemporary and all civilizations are current.

The multimedia exhibit includes, along with a tunnel created using Lightboxes, projections, holograms and monitors, the use of RFID bracelets, which allow the registration of the visitor's interests during the visit and VR station located in the hypogea in Palazzo Lanfranchi in Matera, created to give visitors a virtual visit experience in underground spaces. Using Virtual Reality headsets, a 360-degree video in subjective point of view can be watched, making the not easily reachable areas of the visiting path enjoyable to all.

## The role of digital experience

The role of digital technologies is profoundly transforming not only people's daily life but also cultural sectors. There is a growing interest in the world of culture and research for the application of technology in the enhancement of cultural heritage and the use of technological solutions to share and spread the knowledge of artworks and territories. It is a new way of thinking about cultural enjoyment as an experience.

ETT has focused its activities for this project on the search for the most suitable technological solutions for the individual project, designing a multimedia and immersive path aimed to creating valid experiences and the enhancement of the visitor experience. By being active for years in the New Media sector, ETT has developed a wide expertise in creating innovative applications exploiting the potential of new technologies in contexts related to edutainment, culture and tourism. By combining original design, storytelling and cutting-edge technologies to create engaging experiences for museums, the focus of the project design process is on taking care of the users, with the main purpose of giving them immersive experiences. The customer and his needs are at the heart of ETT's projects, which are built trough customized design and technology solutions.

In fact, it is not obvious that there is only one approach to follow in the creation of cultural experiences: the choice of the multimedia solutions to be adopted is strictly linked to a deep knowledge of the specific contents and a detailed analysis of the project. According to modern museology theory, in recent years, the trend towards improving the visitor experience has taken a great leap forward. We are entering a new era in museum design as the technologies for immersive, interactive experiences become more sophisticated and widespread. This new approach to museum exhibitions is based on the use of the most recent technologies and devices in order to enhance visitor engagement and interaction; give visitors an active role to play and define the goal of an "immersive museum". The aim is to revitalise communication with visitors, transforming them from passive to active forces through an "immersive" experience. Modern literature implies that all forces operating in the culture sector, should not attempt to provide experiences of value to passive visitors, but rather should incorporate value into the co-creation process through interaction. The traditional experience at the museum is gradually turning into an emotional event, which means that technologies like simulations, gaming and virtual reality represent some of the new methods to use to increase participation and involvement.

With the increase in competition on a global scale and the emulation of experiences, the cultural sector must also explore in a structured way the new opportunities related to the co-creation and use of technologies, in order to dynamically create “enhanced” experiences. Technology is therefore configured as a mediator of experience and at the same time its use becomes experience itself. With this project we have therefore achieved an innovative experience that offers elements of surprise, generates knowledge and involves the visitor on several cognitive levels.

The multimedia solutions designed for the Ars Excavandi project offer a new way to know the art and practices of excavation that have given rise to architectures, civilisations and rocky landscapes through the centuries. In particular, the design of the project Ars Excavandi involved the development of different multimedia experiences, such as gaming, video projection and virtual reality, that employ different forms of interaction with the public.

The main challenge that has been faced during the project design period has been related to the fact that the original exhibition concept did not contemplate the presence of physical antique objects. The curator wanted to create an immersive journey through time and space by using only multimedia tools. This design choice has had a profound impact on the final user experience. On one hand, the visitor has the chance to completely enjoy the emotional and didactic multimedia environment, exploring a different cultural approach in opposition to the classic museum experience. On the other hand, the multimedia exhibits have been designed to use different technologies and physical set-up solutions, e.g. projections, lightboxes, monitors, to create an organic yet differentiated visiting experience. The main design choice revolved around the concept of choosing the most suitable technological solution for the different topics of the exhibition, by analysing the sub-topics of the path.

During the visit different multimedia experiences are presented. The visit in the route is modelled through different sensory experiences indicated by colours, sounds and odours which allow the visitor to immediately identify the different themes presented and to increase the participation, memory and involvement of visitors. An experience where different senses are engaged, sight, hearing, smell and an emotional component dictated by images and videos, which provide an additional sensory, cognitive and relational value.

The use of different devices, manages to capture and keep active the attention of the users who are encouraged to interact with the contents, as in the case of touchless devices. The RFID bracelet is intended to generate an interaction between the installation and the visitor who, through his choices during the visit, will generate his own personal experience in the museum, which will then be described through a final digital certificate. At the end of the multimedia path in Palazzo Lanfranchi, the visitor is invited to take a virtual visit with a 360-degree video of the hypogeum of the building.

With the development of technology, the virtual dimension has grown, offering spaces and experiences that go beyond architectural spaces and beyond museum collection limits. It is precisely this possibility that has led to the creation of the Virtual Reality experience that allows the visitor to immerse himself in a simulated environment, while always remaining stationary, with a vision of accessibility to the site.

The different areas of the multimedia exhibit are presented below, as well as the subdivision of the room with the different suggestions presented to the visitor.

**Who we are? The questions of the exhibition and the interactive game**

The exhibition aims to stimulate the curiosity of visitors through a series of questions that will be answered during the exhibition. Why was the first excavation done? Are the art and thinking of caves current? What is the oldest city in the world? An interactive game will be organized along the way. Who are we? which poses similar questions to visitors who can participate thanks to a RIFD bracelet.

Technology is often used to create moments of interaction that encourage connections between visitors and installations or exhibits. The RFID technology is a simple method to promote a cognitive interaction and offer a simple interface between people and digital installations and this is an accessible technology for all visitors. The interaction is therefore based on the individual's physical proximity to the panel or video. This speeds up the information flow and allows the visitor to interact quickly. The game ends with the answer that we are what we know and the visitor will receive a certificate of Digital Nomad indicating his degree of universal empathy with the figure that identifies him to one of the characters of the exhibition and can therefore be one or one: Perceptual Neanderthal; Sapiens Innovator; Discoverer Shaman; Paleo Astronaut.

The method of interaction with the insertion of gamification elements, is based on the principle of edutainment, in other words the conjugation of educational content in a playful context (entertainment), which allows not only to emphasize the sense of "discovery" that a museum can evoke, but also to test the effectiveness of the communication processes implemented by the museum and the engagement produced on the visitor.

## The museum route

The exhibition was arranged as a space-time tunnel within the National Archaeological Museum "Domenico Ridola" in Matera. The steel tunnel, together with the lightbox fabric built specifically for the exhibition, was designed as a break from traditional museum spaces. As a result, visitors go through the tunnel into a dimension, not of this time and space, and are lead along a path of sound, smell and visual suggestion that helps them to discover the art of excavation from which architecture, civilization and rocky settings derived over many centuries.

The exhibition is organised in five stages, each of which is characterised by an element (air, fire, eros, water and earth), by a colour (yellow, red, ultraviolet, blue and green) and by a series of sounds and fragrances that guide the visitor through the multimedia journey; all revealed to their eyes and ears, one stage at a time.

This installation has been conceived with a view to post-experience, with the aim of re-elaborating the contents observed and recalling the memory of the emotions experienced during fruition, thanks to the different sensorial planes that create in the visitor a real immersion in the contents.

**Stage 1 – In the brain cavern**

*White-Yellow color, Air element, jasmine scent*

The space without dimensions of the caves makes one reflect on the concept of time whose illusory nature has been demonstrated by Einstein and on the role that perception plays in the reconstruction of events. From Plato's myth to the dark room invented by the Arab Al Azhem in the tenth century and used by the masters of the Renaissance up to the invention of cinema and holograms, the projections show that vision and interpretation depend on how we perceive and know. Entering the hall, visitors pass in front of a light source which casts their shadows on the opposite wall. The projection of the shadows of the visitors on the two walls reveals a series of rear-projected images that float as if suspended and reflect Plato's myth. The more people there are in the room the more their shadows reveal the rear-projected image.

In the room there is also a monitor on the history of Al-Hassan Ibn al-Haytham as a starting point for reflection on the evolution of optics as a modern science.


*Fig. 1. Ars Excavandi Logo (© ETT).*

**Stage 2 – Alliance and symbiosis**

*Red color, Fire element, benzoin scent, sound of explosions*

Our species has been successful through migration and art. The conventional image of evolution as a linear progression from hominids towards current physical appearances is false. Evolution is best represented by a series of branches, crossings, and contaminations. Humanity survived through co-evolution and symbiosis. In this evolutionary line, the invention of fire represented a fundamental step for the evolution of humanity itself, as can also be seen from the monitor which proposes a video on the discovery of fire. Instead, in the projection, Prometheus appears in the shadows from the darkness, holding the fire to be given to men hidden in a ferrule. Prometheus is the mediating hero between divinities and men. He is the first shaman, visionary sorcerer who breaks the rules. It is the period of the great cave art witnessed by the Lascaux cave dating back to 15,500 BC. which is shown in the other projection that focuses on the figure of the bull. The bull is present in later mythologies as a symbol of the cosmic principle (see Fig. 2).


*Fig. 2. A lightbox and the projection of stage 2 Lascaux paintings (© ETT).*

**Stage 3 – The Creator Sound**

Culture, the cosmos-vision and the conceptions of the communities have determined the transformation process and the technological revolution. The singularity of the Big bang, which originates the shape of the space-time universe, is anticipated in the myths of creation with the representations of buffaloes in the Palaeolithic caves. In the first projection, starting from a black screen, the expansion of the Universe from the Big Bang is simulated according to a representation of expanding lights and galaxies.

In the monitor, a looped video shows the destruction of the chariot of the Madonna della Bruna which is repeated cyclically every 2nd July. There is also a projection in the room that shows a black screen, followed by the Big Bang and the expansion of the Universe, with its lights and galaxies.


*Fig. 3 The Creator Sound in stage 3 (© ETT).*

**Stage 4 – Water labyrinth**

*Blue color, water element, lotus flower scent, sound of water shower*

Water is the vital principle, creative and destructive force. Its management is fundamental for the creation of the first settlements. In the first projection, a map is displayed that shows the spread of Neolithic culture and focuses on the main settlement sites, Jericho, Harappa, Murgia Timone, Ur, Stonehenge, Menfi, Hili, Dilmun, Troia, Knossos. The second projection takes up the importance of this element through the reproduction of a cascade of water. Another monitor shows an in-depth video on the symbiosis between the city of Petra and Matera.

**Stage 5 – Matera matrix**

*Green color, Earth element, mauve perfume*

The final stage of the journey deals with the importance of the underground world, linked to the symbolism of vegetation and rebirth. In the room, a projection shows a series of underground images, which then pans out to a panoramic view of Matera and continues outwards until Mars comes into view.

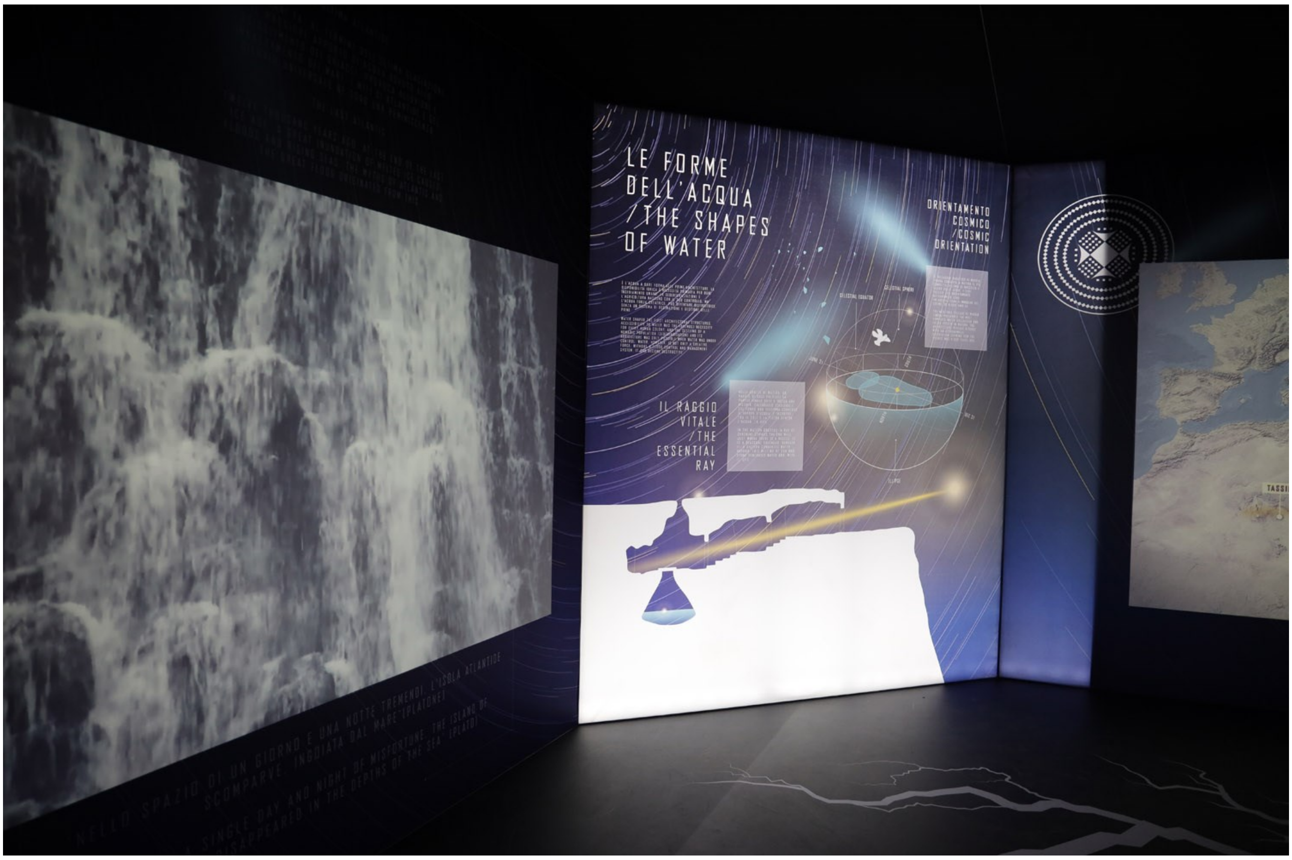


*Fig. 4. Waterfall Projection and lightbox in stage 4 (© ETT).*

## The Lanfranchi Hypogea: VR Application

Many places can boast of being the first settlements in the world and some are older than Matera. But what makes Matera unique, among cities dug out of the rock, is the fact that it is still and once again being inhabited, making it a symbol of a fall and renaissance, of community and resilient culture. The rocky city of Matera was completely emptied because modernity considered those ways of living inadequate for consumeristic development. In 1993, it was the first city in the South of Italy to be included in the UNESCO World Heritage list. The inscription was achieved by creating a new narrative and vision that started up the recovery process up to the point of its current success. The 1972 UNESCO Heritage Convention was set up after an international movement that took place to save the underground temples of Abu Simbel in Egypt, which were dismantled and repositioned higher up, to save them from flooding caused by the construction of a dam on the River Nile.

While rebuilding the temples, an artificial underground chamber was created and the original astronomic orientation was maintained, so as to allow a ray of sunlight to illuminate the statues of the gods twice a year. The restoration designers therefore showed awareness and accuracy in conserving the relations of the site with the environment, the cosmos and the spirit of the work. However, nowadays we would not move the temples. Instead we would fight to prevent the dam that flooded a large part of Nubia and caused serious damage to the Nile's and Mediterranean's eco-system being built. That is why, through its experts and candidacies, UNESCO constantly renews its concept and theory of protecting Heritage. This was originally based on the ambition of universalism, on separating natural and cultural heritage, on authenticity, excellence and a museum-like vision.

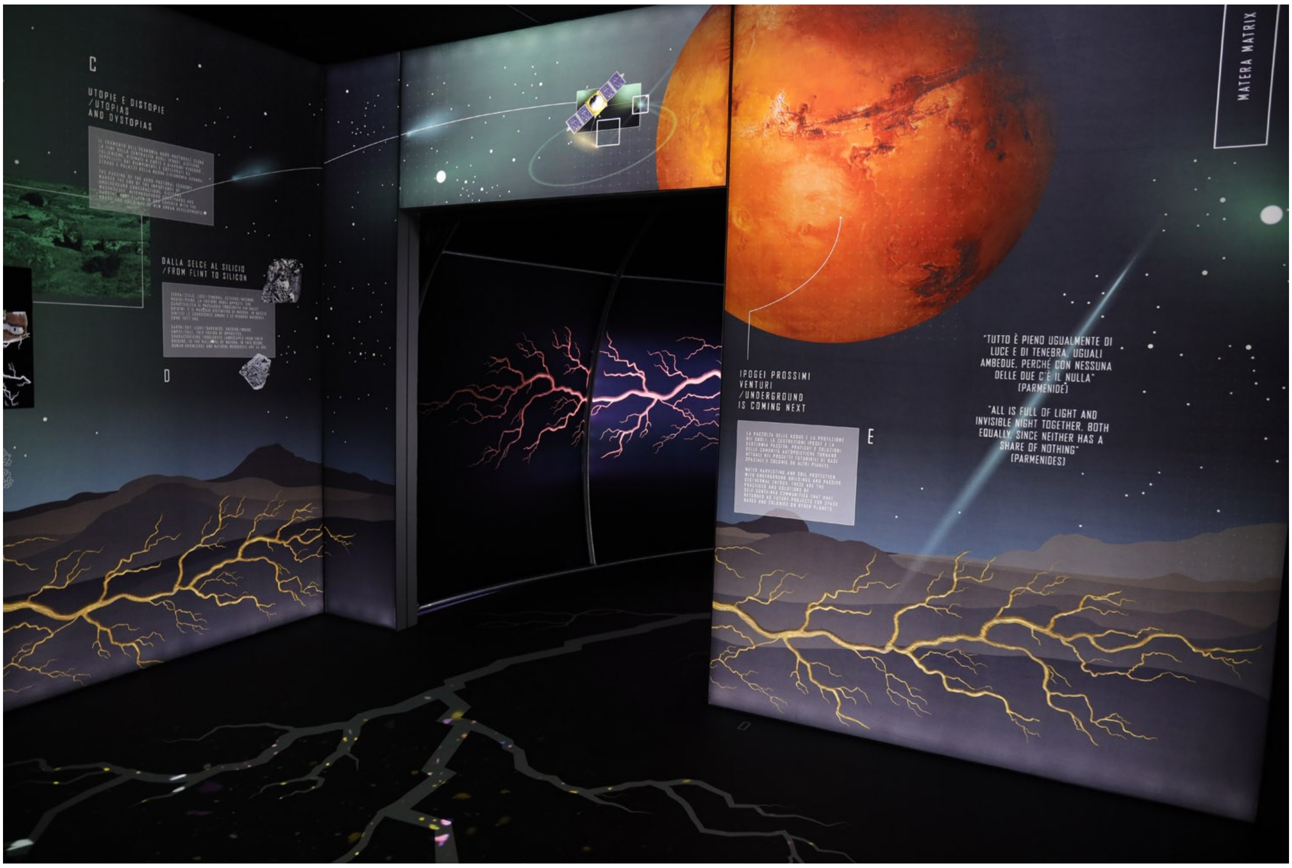


*Fig. 5. Mars Underground on lightbox in stage 5 (© ETT).*

Today, after the inclusion of Matera and the entry of several countries into the Convention that bring different cultures, these principles have been replaced by multi-culturalism and diversity; a holistic vision; management processes, that are a priority compared to interventions to create museums; a continuation of knowledge and asset production processes; the elimination of hierarchies of value between grand monuments and popular expressions. The inhabitants came back to Matera using ancient construction techniques for renovations and managing to reconcile ancient architecture with the new techniques required for the standards of today's life. The traditional techniques of collecting water, protecting the ground, living in caves, natural architecture, passive geo-thermics, the type of urban structure, are now a model for the most advanced research in bio-architecture, sustainable cities and green economy. The global, climatic, environmental and economic crisis, and the social dramas of poverty, migrations and destruction of cultural and biological diversity make it even more urgent to direct development differently. The creation of new models may arise from ways of thinking that were marginalised by modernity, such as those of self-sustainable rock communities. In rock shelters and in the depths of caves, the first artists' representations were created, giving a message that revolutionised perception, the senses and categories of knowledge. Listening to and thinking about the cavernous landscape today means shifting attention from places to knowledge and the people that have managed it; drawing on a troglodyte thought of saving resources, labyrinth-like, nomadic, passive, slow, a bearer of transversality, inclusion, multiculturalism and symbiosis. The teachings and warnings from this ancient art of excavation are engraved in the cities of stone, marked on their faces and sculpted into the hearts of their custodian communities.

The virtual reality application, created for the hypogea of Palazzo Lanfranchi in Matera, allows visitors to experience a virtual and interactive visit of the underground spaces, thanks to 360° shots of the rooms enjoyed by viewers, which brings the visitor back to the history and beauty of this place at first glance. The VR exhibit creates a totally immersive experience that involves a high emotional involvement of visitors, thanks also to the POV-*Point of View* technique, a very powerful tool that allows users to experience the scene in first person and feel part of the story told, facilitating thus the learning process and creating a memorable and multisensory experience.

The virtual visit to the hypogea of Palazzo Lanfranchi allows visitors to overcome the architectural barriers that the hypogea have due to their intrinsic nature and to guarantee the virtual accessibility to this priceless heritage even of the weak social categories that would otherwise be excluded from the museum visit experience in due to a physical disability.

Thanks to the application of virtual reality, visitors will be able to experience a sense of reality never perceived before and will therefore have an experience almost entirely comparable to the direct one that will allow you to discover even the most secret corners of the hypogea.

## Conclusion

We accepted the challenge of creating a challenging place, with projections, lightboxes, monitors, sounds and smells, in which visitors are no longer passive users, but prosumers; interacting with technology and actively participating directly in the multimedia exhibition. They generate sounds and shadows, also letting themselves be guided by smells and by the visual suggestions evoked by the images shown.

Today, as never before, multimedia is part of our daily lives. There is a growing interest in the world of culture, and the need to discover new ways of sharing and spreading our heritage is emerging as a compelling task. It is a new way of thinking about cultural enjoyment as an experience, not only participatory, but also completely immersive. Technologies are able to redefine the paradigms related to the decisions concerning the exhibition in the physical environments of museums and cultural institutions, remodelled and adapted to accommodate the technological solutions and to enhance the innovative visitor routes that are emerging.

We can trace a profound change and impact of new technologies in museum displays and user experience with the willingness of visitors to interact. In this project, where there are no physical objects on display, multimedia was a fundamental aspect to provide the visitor with memories, information and suggestions that remain beyond the visit.

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# Leonardo da Vinci’s Last Supper

## Storytelling and enjoyment in new ways

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**Abstract:** The year 2019 marks the 500th anniversary of the death of Leonardo da Vinci, a man of genius and universal talent who lived during the Renaissance period and who is universally recognized as the complete embodiment of the spirit of his era. This is the reason why ETT S.p.A. (International Creative and Digital Industry) created the new mobile App dedicated to an undisputed masterpiece, Leonardo da Vinci’s Last Supper, for the *Polo Museale Regionale della Lombardia* (Museums of the Lombardy Region). This mobile App has been designed to increase engagement with various types of audience; ETT’s approach focuses on the use of innovative edutainment tools such as augmented reality.The experience offers increasing levels of information, revealing curiosities and anecdotes on the origin of the painting and its characters. The application is a visit support tool providing information directly to smartphones during every stage of the experience: before, during and after. With this instrument, visitors can really discover the secrets hidden in the Last Supper, one of humanity’s undisputed masterpieces. In addition, the app offers a tourist route through 15 POIs (Point on Interest) to discover locations bounded to Leonardo all around the city of Milan and its neighbouring areas.

***Keywords:*** *augmented reality—mobile app—innovation—history—digital storytelling*

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## Introduction

The Leonardo da Vinci’s Last Supper app, created by ETT S.p.A. for the *Polo Museale Regionale della Lombardia* is a software platform offering a new way to engage multiple audiences through innovative edutainment (educational entertainment) tools as AR (augmented reality). The aim of this app is to deliver information about the painting, the characters and the experimental techniques Leonardo used to create one of his undisputed masterpieces. The application is a visit support tool providing information directly to smartphones (see Fig.1), with this instrument visitors can really discover the secrets hidden in the Last Supper.

*Fig. 1. Visitor scanning a painting with AR (© ETT).*

Visitors cannot stand in the paintings area for more than 15 minutes due conservation reasons, so the app is designed to provide information during every stage of the experience: before, during and after.

## Approach

The project aim was to develop an app that included different routes inside and outside the museum. Outside the museum users can explore Milan and the places bounded to Leonardo's life thanks to a route composed by 15 POIs (Point of Interest) scattered all around the city.

Inside the museum is where AR technology played an important role. As mentioned in the introduction visitors cannot stand in the paintings area for more than fifteen minutes due conservatives and guest's flow reasons. Besides this location cannot host informative panels so, contents needed to be delivered in some other ways.

## App development stages

- Study of UI and UX
- Content analysis and elements definition (Routes, POI, Content, etc)
- Content Structure Design
- CMS Development
- Models and elements development inside the mobile app
- Flow and interactions development

- Graphic UI design and implementation
- iOS and Android Application Tests
- App release on different platform  (App Store & Google Play Store)

## AR integration in the native App

The application core is the possibility to discover how the Last Supper paintings were made, with this aim AR was integrated inside an iOS/Android native app.

To allow this integration several piece of software was used:

Unity: Unity is a cross-platform game engine developed by Unity Technologies, first announced and released in June 2005 at Apple Inc.'s Worldwide Developers Conference as a Mac OS X-exclusive game engine. As of 2018, the engine was extended to support more than 25 platforms. The engine could be used to create three-dimensional, two-dimensional, virtual reality, and augmented reality games, as well as simulations and other experiences. The engine was adopted by industries outside video gaming, such as film, automotive, architecture, engineering and construction.

AR Foundation: AR Foundation allows you to work with augmented reality platforms in a multi-platform way within Unity.

ARKit: ARKit allows developers to build high-detail AR experiences for iPad and iPhone. Environments captured through the device can have animated 3D virtual text, objects and characters added to them. AR scenes made by one individual are persistent and can be seen by others visiting the location later.

ARCore: ARCore is a software development kit developed by Google that allows for augmented reality applications to be built. ARCore uses three key technologies to integrate virtual content with the real world as seen through your phone's camera.

Once the software system had been defined, the painting had to be identified as a marker to allow to trigger the AR once the visitors headed the smartphone to it. Using Adobe Illustrator prospective lines and painting out lines has been drawn and importing them into Adobe After Effects it was possible to create a video that superimposed the lines on the image of the painting. AR has been used in other ways inside the app routes described below.

## The history of the „Last Supper" and the app routes

In 1494, Ludovico il Moro commissioned Leonardo to decorate the refectory of the Church of Santa Maria delle Grazie, a Sforza family religious place. Traditional decorations were chosen for two walls, epitomising the Crucifixion and the Last Supper. Donato Montorfano worked on the Crucifixion, using a traditional setting. On the opposite wall, Leonardo began work on the Last Supper. The artist did not like the fresco technique, as the speed of execution was incompatible with his modus operandi. Colours had to be applied before the plaster dried and fixed them, but Leonardo had continuous second thoughts and was always making additions and small changes. He chose, therefore, to paint on the wall as though it were a tablet, first putting down a rather rough layer of plaster. This experimental technique proved to be unsuitable for the room's humidity and, for this reason, the painting was in a poor state of conservation for centuries. It was restored, as much as possible, during one of the longest renovations in history, lasting from 1978 to 1999 and employing the most advanced techniques in the sector.

The Last Supper mobile App consists of a series of structured routes, diversified depending on various types of target, as described below:

## Perspective and compositional choices

During the latest restoration, a hole was found in Jesus's temple. This links to the nail used by Leonardo as a vanishing point for lines of perspective (Fig. 2). Thanks to augmented reality, we can visually retrace the way the artist set perspective and compositional choices. The lines of perspective converge at the point where the hole was found, revealing how the head of Jesus is the fulcrum of the entire composition. Visitors can thus understand how Leonardo used this illusion to make real architecture coincide with a painted one.

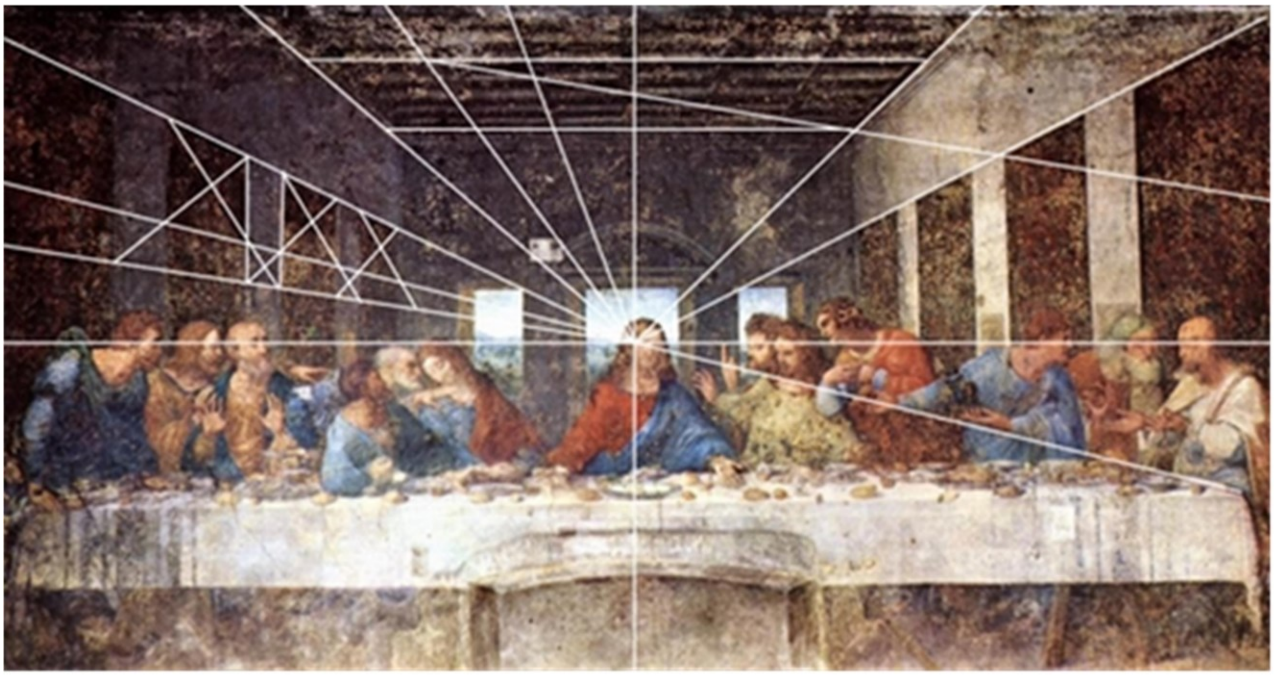
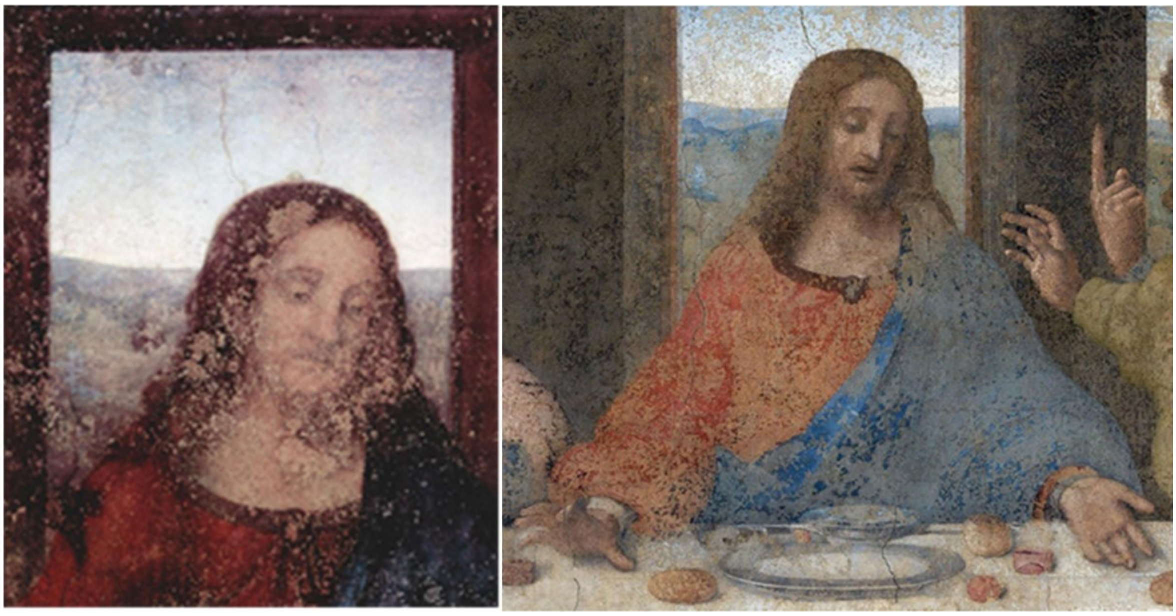


*Fig. 2. The Last Supper's lines of perspective (public domain image https://it.m.wikipedia.org/wiki/Ultima_Cena_(Leonardo)).*

## Restorations and tormented conservation

Augmented reality takes visitors through the conservation history of the work over the centuries. Images appear gradually and are attenuated, giving a sort of Last Supper chronicle in pictures (Fig. 3)



a b

*Fig. 3. a) Christ before and b) after the restoration (public domain image, https://it.m.wikipedia.org/wiki/Ultima_Cena_(Leonardo)).*

## Leonardo's studies for the Last Supper

The multimedia application shows the preparations for the Last Supper in an interactive way. Starting from the high-resolution image of the painting, touch-screen scrolling enables the user to discover the preparatory drawings of the mural painting.

### The great iconographic innovation

An audio track recites the famous Gospel passage in which Jesus announces his betrayal, with an explanation of the meaning of some of the details, e.g. Judas's money bag and Peter's knife. A gallery with some pictures relating to other famous fifteenth-century last suppers helps us understand the innovative advances of Leonardo's work.


*Fig. 4. Details explained through Augmented Reality (© ETT).*

## Leonardo's operational technique and the conservation problems

The audio/video track explains the fresco process, emphasizing the differences from the experimental technique used by Leonardo and revealing the reasons behind its precarious state of conservation.

As well as the normal visit routes, the App also includes a route for visitors with accessibility issues and another one for families with children. An audio track, automatically activated by a beacon located near a tactile model of the Last Supper, supplies a narrative for the visually impaired, increasing inclusion.

The route for families with children is of a more playful kind, with gaming to stimulate their curiosity and imagination, such as the one with which a work of art may be created by choosing the technique (fresco, tempera or oil painting) and the colours to be used. Another game leads to the discovery of the colours of the Last Supper, starting from a black and white version of the painting.

Designed this way, the application is a versatile tool involving various categories of the general public. Visitors are provided with further information also before and after the tour. Routes are diversified, taking into account different user targets and people with accessibility issues, and the multi-language content helps international visitors. Information-gathering profiles collect visitor feedback and strengthen the use of social networks as a sharing and promotional tool.

By using this tool, visitors will be able to discover curiosities and the anecdotes that lie behind one of the undisputed masterpieces in the history of art, which is included in the list of UNESCO World Heritage Sites.

## Multiple Routes for Different Audiences

Alongside the main routes just described, the app is designed to deliver more content to a more extended audience. Developing the app have been identified four categories:

- Casual Visitors
- Art/History Enthusiasts
- Children
- City Breakers

### Interactive Guide for everyone

As mentioned in the previous section one of the identified categories is the „casual users" one. All those users who approach the museum without a particular preparation in the historical / artistic field belong to this category. Through the interactive guide, they can learn all they need to understand this masterpiece before, during and after the visit. So the core route is design mainly for this kind of users, inviting them to discover all the others app section to know more about historical context, art techniques and the city where the painting is hosted.

### "Stories" for Art Enthusiasts

For art and history enthusiasts has been created the "stories" section, this can be consulted before and after the visit to the museum and allows to deepen the historical and social context in which "The Last Supper" was created. This section is composed of 12 POIs and explores Leonardo's relationship with the Sforza family; the methods of preparation and creation of the painting; the restoration of the work and the history of the museum. Keeping the application installed on their devices and browsing inside it, even casual visitors can approach these contents and turn into enthusiasts.

### Gamification and Edutainment for Children

For children, a parallel path to the main one has been designed, which is divided into 6 POIs:

- A bit of History! Is where Leonardo in first person talks to children. He presents himself, his work and his biography in a simple and "kids friendly" way.
- Let's discover the Last Supper! Is a section with video content that explains the masterpiece to children in a simple and funny way
- Colour Me! is the first video game in which the child will find himself having to recolour faded parts of the "Last Supper", therefore having to observe the work carefully during the visit to find the missing colours
- Guess Who is the second videogame in this section: the works displayed at the museum will appear and the user will have the task of recognizing which ones are by Leonardo, and which from other authors.
- At the Studio allows the user to identify himself in the artist's shoes by placing all his tools at disposal to create his own piece of art
- Puzzle is a game in which several works of art by Leonardo will be placed in front of the user, who will have to reassemble them in order to know the title.

## Leonardo's Itineraries for City Breakers

In the design of the application routes, the category of city breakers was also taken into consideration: those who visit cities of art and culture around the world. Thinking above all of these, the section dedicated to the Leonardo's Itineraries were created. This function allows users to cover 15 POIs related to Leonardo's history in Milan, passing through places outside the mainstream routes of mass tourism. Obviously, this sort of guide for the city of Milan can be interesting even for the occasional user who will be able to get to know the city and its wonders. The "Leonardo Itineraries POIs are:

- Sforza Castle
- Monument to Leonardo, Piazza della Scala
- Ambrosiana Library
- San Siro Racecourse
- "Leonardo Da Vinci" Science and Technology Museum
- Mora Bassa Mill, Vigevano
- State Archive
- Cascina Bolla in via Paris Bordo
- Leonardo's Ferry Boat, Imbersa
- Leonardo's Vineyards, Casa degli Atellani
- Trivulziana Library
- Conca dell'Incoronata
- Villa Melzi, Vaprio d'Adda
- Pinacoteca Ambrosiana (picture gallery)
- Pinacoteca di Brera (picture gallery)

## Using screenwriting techniques to engage the audience

The application was designed following the structure typical of cinematic narratives. Above all, Syd Field's paradigm was used, which divides the narration in three acts within each of which hooks are identified narratives that will be a pretext for the plot points.

The narration also takes shape thanks to the use of some of the narrative functions of Vladimir Propp, which the anthropologist schematized as basic elements common to many fairy tales in different cultures.

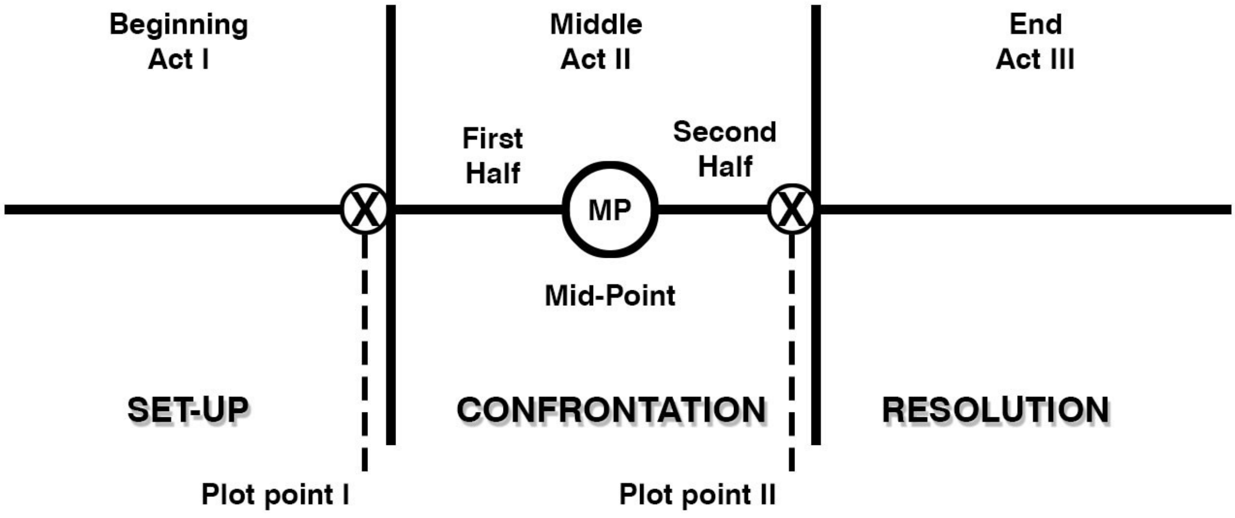



*Fig. 5. The Syd Field Paradigm.*

The pre-visit itinerary is therefore configured as the first act of the narration. The planning of the itinerary therefore outlines the characters of the story: Leonardo and Ludovico il Moro. The story then begins with Leonardo's arrival in Milan at Ludovico's court, at his work as a military engineer and the artist's relationship with the city.

Now to the user is offered the history of the commissioning of the work and also of the place where it was made. This is used as a narrative hook for the second act: the visit to the museum.

As mentioned, the in-museum visit route is the act II of this storytelling. When the visitor enters the Museums, them already know the historical and cultural context. During the visit visitors can discover the real main character of this narration: The Last Supper.

Once the visitor has known the man, the context and the works, he is ready to discover the impact of his work on the history of the city. Thus, the Leonardeschi itineraries serve as the third act of the narrative.

## Conclusion

The challenge was to develop an information architecture that was able to deliver contents just at the right time. Allowing visitors to reach this masterpiece with awareness but at the same time, showing its secrets in the very moment they stand in front of it. The analysis tools had to be serviceable and intuitive to make visitors able to prepare for the visit wherever they are. Moreover, being the work of Leonardo universal, the app's user experience had to be able to talk to visitors from all around the world, of all ages, education level and backgrounds. ETT conceived a product that guides the visitors, before meeting the painting, into the Leonardo's world.

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# The majolica collection of the Museum of Bargello

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**Abstract:** Nowadays art exhibitions cannot just show art objects, they need to involve visitors emotionally. Museum users are not just scholars and experts looking for facts; many visitors want emotions and multidisciplinary experiences. These new requirements, together with the need to protect art collections from possible dangers (such as effect of time, natural disasters, and human attacks), mean that technology needs to play a crucial role in the design of an exhibition layout, which requires the involvement of many different technical and artistic fields of knowledge. This research is focused on the design of the majolica collection exhibited in the Bargello Museum in Florence, which was founded in 1865 as the first national museum in Italy. The current curators have to deal with a double need: *i)* to refresh the exhibition, in order to preserve the high profile of the museum, and to optimize the expressive potentiality of each exhibited object; and *ii)* to protect the art collections, ensuring each item's safety. The Majolica Room is the next exhibition room to be renewed in the museum. The display dates from the 1980s and thus does not comply anymore with the current administrative requirements. The design of the new exhibition requires special attention, due to the fragility of the items and to their variety in terms of shape, dimensions, and relevance. The experience was developed within the RESIMUS research project (Viti and Tanganelli, 2019), focused on the resilience of art collections, and it involved didactic activity with students from the School of Architecture in Florence.

***Keywords:*** *Museum of Bargello—Majolica collection—design of Museums staging—seismic safety of art collections*

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## Introduction

Art collections are a crucial part of the cultural identity of communities, and also of their economic assets. Florence, as well as many other towns in Italy and the rest of the world, owes its fame to its architectural and artistic heritage. It hosts several art collections, both private and public, most of which are displayed in historical buildings. The use of monumental palaces as art museums does enhance the potentiality of art exhibitions; nevertheless, it forces the designer to make a choice about the relationship between the collections and the architecture, as each deserves the whole attention of the viewer.

Moreover, visitors' expectations regarding art exhibitions have grown a lot in these past years. The ability to see art exhibitions in books, on websites, and other global platforms makes people more demanding and abler to appreciate the quality of the setting. This ever-increasing standard requires a similar ever-increasing attention to an exhibition's display design.

This paper presents a didactic experience whose objective was to propose a new display layout for an art collection, but also to enhance the participating students' background by asking them to immerse themselves in a complex and multidisciplinary experience. The teaching contents included not only design, but also technology (for an accurate selection of materials and technical devices) and structural engineering (to ensure the collections' seismic safety). The design work was focused on the Majolica Room of the Bargello Museum in Florence. The interest in the room arose not only from the museum curators' specific request, but also from the challenge posed by the fragility and the multitude of the works and the consequent difficulty in achieving a safe and effective display.

The building that hosts the museum, shown in Fig. 1, is one of the oldest in Florence. It dates back to the middle of the 13th century and played a crucial role in the political and social development of the town until it became the first Italian National Museum (Giorgi and Matracchi, 2006) in 1865. Since then, many exhibitions have been on display; at present, the museum hosts some of the most valuable marble sculptures of the Tuscan Renaissance, besides the majolica and the ivory collections, and many other art objects.

*Fig. 1. Museum of Bargello: external views (© authors).*

The current layout of the Majolica Room, situated in a corner of the first floor of the building (see Fig. 2a), was established in 1983, even if it has been modified since then. The room has a quadrangular shape, with a decorative pattern of coats of arms at the top of the walls, along the entire perimeter (see Fig. 2b).

The entrance is on one of the smaller sides, while on one of the longitudinal walls there are two big windows. Even the ceiling has an important impact on the aesthetic feeling of the room—it is coffered, with big, ancient timber beams.

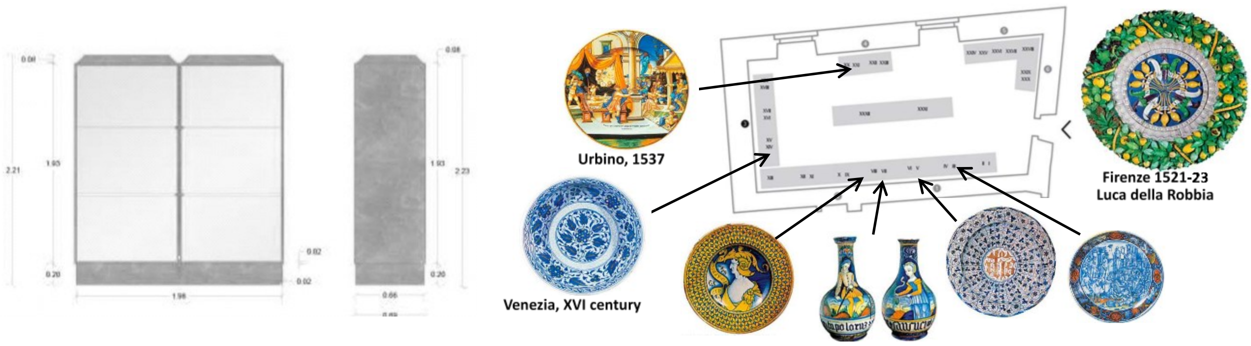
*a* *b*

*Fig. 2. Majolica room at the Museum of Bargello of Florence: a. position of the room within the Museum plan b. view of the room (© authors).*

## The current setting and its main shortcomings

A comprehensive analysis of the current setting was undertaken before the design stage. The curator of the collection was available to help the students during this phase, providing information on the museum operators' discontent with the majolica staging.

Fig. 3 shows the current arrangement of the display. The staging devices consist of brass and glass cabinets (Fig. 3a) placed along the walls and in the middle of the room. The collection comprises all types of ceramics, from apothecary jars to tableware and decorative pieces, including some items of the rare "Medici porcelain" and a group of pieces from Urbino (see Fig. 3b).




*a* *b*

*Fig. 3. The majolica collection: a. One of the shelves of the room, b. some of the artifacts shown in the collection (© authors).*

The analysis of the current display highlighted three main aspects for improvement. The first concerns the exhibition layout, which is antiquated, as it follows the criterion of showing as many pieces as possible. Such logic is acceptable for an audience of scholars, since it fulfills the need to provide comprehensive documentation, but it is not satisfactory as regards the emotional impact of the collection and the involvement of a generalist visitor according to the most recent museographic trends. It is necessary to create an “artistic path” for the items’ display, which currently has no proper hierarchy and thus visitors cannot understand, without a dedicate effort, which are the most precious objects of the collection.

Another aspect regards the lighting of the room, which is in part natural, coming from the two windows, and in part provided by lighting devices (Fig. 4).

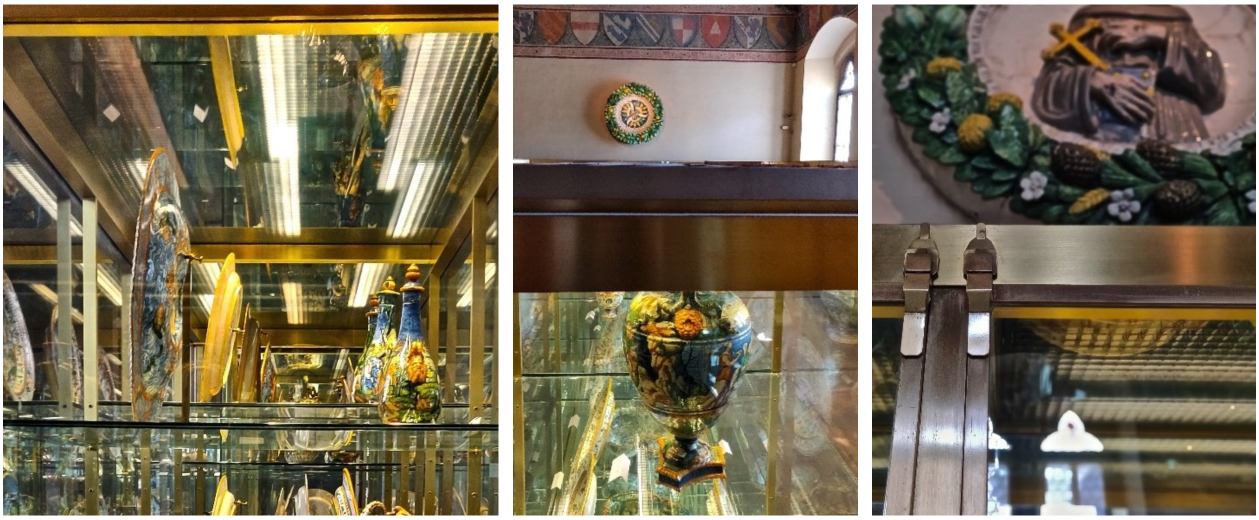


*Fig. 4. Lighting of the majolica staging (© authors).*

The sources of artificial light are diffused and homogenous, not calibrated on individual objects and without a correct chromatic tone for the best color result. The soft light, without shadow contrast, does not help visitors appreciate the collection and does not enhance the most important pieces. The natural light, meanwhile, depends on the season, the weather, and the hour of the day and it cannot be controlled to offer appropriate viewing conditions. For this reason, in many museums natural light is used in few spaces only for specific art pieces. Furthermore, the cabinets containing the items do not comply with the current standards. They have glass shelves and mirror backdrops that do not provide a proper background for the objects (see Fig. 5), and they are difficult to manage, as they are very heavy. They are located along the walls and in the middle of the room, according to the criterion of maximizing the exhibiting space, but without any balance with the architectural and evocative characteristics of the room.

The final aspect concerns the information apparatus. The descriptive captions consist of paper labels placed near the objects, according to a widely used method. However, these labels are not consistent with the general setup, they create visual confusion, and are not reader-friendly. There are no multimedia devices or information panels either.

*Fig. 5. Reflection effects of the staging (© authors).*

## The proposals for the new display

The design proposals were developed within the class considering the shortcomings uncovered during the analysis. Before starting individual work, the students were required to discuss all the issues together, in order to provide some common guidelines for the project.

The students reiterated the idea that in contemporary museum spaces the simple function of showing must be combined with an emotional experience of reading about and understanding works of art—a fundamental element of the design process. Museum visitors are an increasingly large and differentiated community that is less and less starkly divided into scholars and amateurs. Consequently, museum design must adopt a variety of techniques that attract the visitor's interest on multiple levels.

The need to renew an exhibition theme is also associated with the need to safeguard its artistic heritage. These two strategic aspects must be part of a unitary design and intervention philosophy, involving a multiplicity of technical and artistic skills.

Space design skills must be integrated and enriched with a technical dimension aimed at safeguarding the art works and with the resilience of the museum system in terms of catastrophic events. This methodology can be easily applied in new museums, but for museum structures housed in historical buildings. It is more difficult to do so. However, there are examples of excellent achievements, such as the Opera Duomo Museum in Florence refurbished in 2015 (https://duomo.firenze.it/en/discover/opera-duomo-museum).

The students' brainstorming session uncovered several specific issues:

- The staging devices should be independent from the architectural context; a lack of continuity between the staging and the walls was chosen to limit the interactions between the two systems; this discrepancy between the architecture and the display could be achieved by introducing an "artificial" floor, which—according to standards—could stabilize the exhibition system, besides introducing a damping layer below the staging devices to improve their stability.
- The new "artificial floor" should be fully accessible from the room entrance through a platform with a slope of 3–5 %.

- Lighting should be provided by proper devices only and exclude the natural light coming from the windows, to improve the final result and to better calibrate the light amount depending on the type of exhibition and items.
- Proper backdrops, selected on the basis of their color and material, should be introduced to reduce reflection issues, enhance the visual perception of the ceramic objects, and valorize the masterpieces.
- The materials and the design of the staging must match the historical context accurately; they should have a contemporary look but, at the same time, be compatible with the wooden ceiling and the painted frame around the walls.
- The shelves should be easily accessible for cleaning the artifacts and changing their position. Furthermore, they must be designed so as to avoid the mutual shading of the ceramics.
- A new information system should be designed and positioned near the entrance door and in the most relevant parts of the exhibition to introduce the thematic areas of the staging.

The selection of the shelf materials and of the lighting devices required a collective effort from the students. When the general guidelines and the materials to use in the project were agreed upon, each student was required to develop his/her own proposal for the display.

The process of developing a concept to achieve a definite presentation is not easy to complete in few weeks; however, this had to be finished within one semester. Therefore, it was decided to group individual proposals into a few main concepts. The final choice ran between two proposals, differing from each other in terms of space and layout, through both were based on simple and symmetrical geometric schemes.

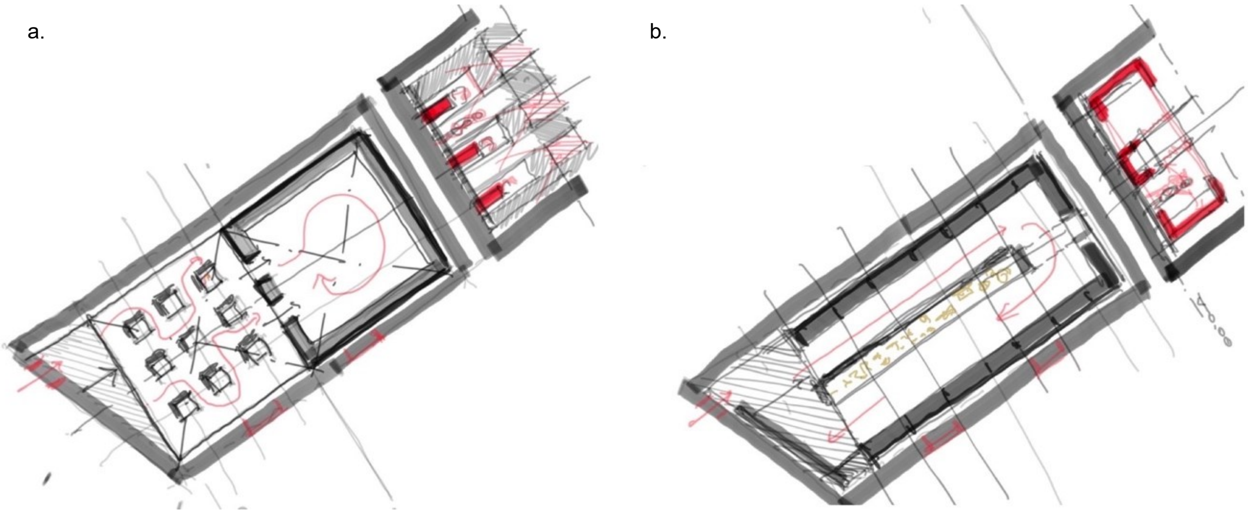



*Fig. 6. Layouts of the two display proposals (© authors).*

The first concept, shown in Fig. 6a, proposed the functional organization of classical temples and split the room into two square spaces, the "pronaos" and the "cell," dimensionally equal to each other and based on a modular grid of 60 × 60 centimeters, but differing in terms of exhibited collections and proposed experiences.

The first square room consists of 9 columns that evoke the space in front of the entrance to a temple. Each column is encased in a glass box mounted with silicone joints to minimize the visual impact of the frames. The rectangular glass cases are lit up by big lampshades made of brass net, hanging from the ceiling. The lampshades have the same shape as the glass cases to suggest the image of continuous columns going straight from floor to the ceiling. The visiting experience in this part of the exhibition is an unobstructed walk around the objects displayed inside the column cases.

The surrounding walls are painted in opaque dark gray tempera. On the wall to the right of the entrance, there are general information texts and the map of the room indicating the position of the collections, with letters applied directly on the wall surface. The floor plans and titles are in gold, the body text in light gray. Next to the texts there is a multimedia screen with a touchscreen for more extensive information on each collection, and films about the history of the main ceramic manufactures, their places of production, and origin.

The second room is more "intimate" and contains the most precious items of the collection. The showcases are placed all along the perimeter of the "cell" surrounding the visitors and involving them in an emotionally engaging experience. The exhibition space is dark and the art objects are enhanced by the scenic lighting. All the elevation elements are made of wood painted in opaque black and emerge, like a section design, from cuts in the solid brass of the artificial floor. False ceilings and lampshades are made from brass net to dissimulate the lighting system. In this part of the room there are no video devices, so as not to alter the perception of immovable sacredness imparted by the objects on display.

The second concept, shown in Fig. 6b, uses the whole room as a single space, with an elongated display that evokes the Medicis' table and their convivial environment. The central display is a single "ribbon" which emerges from the floor and ends on the front wall of the room, becoming a vertical case for plates and flat artworks. All around the walls there is a continuous staging system, based on a module that is repeated to create the entire device setup. The showcases are deployed along the room perimeter with a big "C" section. The elementary geometric form is designed to solve the main needs of the exhibition: fixing the shelves and holding the LED lighting systems. The exhibited items are protected by full-height frameless glass windows.

The finish of the display structure and background surfaces is opaque concrete gray resin (gray is one of the most compliant colors with the brilliant color palette of antique ceramics) that resembles the typical Florentine gray stone, the *pietra serena* used by Filippo Brunelleschi for his Renaissance buildings (Vasari, 1550). The wooden structure of the artificial floor is covered with raw iron sheets—a contemporary finish with a medieval flavor.

The general information panels are on the back wall and are visible from the entrance to the room. On the sides of the central display case, in a vertical extension of the showcase located in the middle of the room, there are two recessed interactive video screens. To avoid the TV-like effect, they are integrated, as if they were images, into the text on the wall. Regarding the information system, neither proposal goes beyond identifying locations for the texts and multimedia equipment, and describing their basic style. In fact, these aspects were pushed back to a more advanced stage of the design, as they required further discussions with the curator and the management as well as more information on the quality and type of contents or visit itineraries they would suggest.

Another issue faced during the class was the seismic safety of the collections and their displays. The most common interventions for protecting art works from seismic hazards can be carried out at different levels (Lowry et al., 2007, Podany, 2015; McKenzie et al., 2007): i) at item level, by preventing the collapse/overturning of each item through proper devices; ii) at window/staging level, by changing the dynamic response of the showcases, avoiding the acceleration and displacement of the items; and iii) at building (foundation) level, by controlling the dynamic response of the building and avoiding any acceleration and displacement in the content.

In this project, the seismic performance of the building was not considered, since its complexity would be beyond the participating students' knowledge. The seismic protection of the items, therefore, had to be handled either at item or window/staging level. The most suitable approach consisted of introducing a base isolation system under the floor of the display.

Both setup proposals are in fact conceived as a single large exhibition where the different elements are connected with each other, but only in a subsequent executive design phase can this concept be perfected by studying sliding connections and resilient joints that use techniques and systems already widely available on the components market. Indeed, an intervention at object scale would be, in this case, difficult to pursue, due to the large number of objects and their shape and dimension diversity. Instead, isolating the staging between the floor and the walls would be compatible with the students' choice to keep the display separated by architectural context.

The two concepts were the basis for a subsequent discussion with the museum management and the curators. The details, as well as the graphic and multimedia information and the cost evaluation, will be established at a later stage, once the preferred layout is agreed with the client. After all, real-life operations development takes longer and requires more specialized and advanced skills. This method has been applied to research currently conducted by the authors with other museums, confirming the need for a much more extended commitment over time and with an additional effort from students. Fig. 7 and 8 show, respectively, the drafts of the two proposals.

## Conclusive remarks

This paper has presented a didactic experience carried out with students from the School of Architecture, whose objective was to propose a safe and formally adequate layout design for an art collection exhibited in the Majolica Room of the Bargello Museum in Florence.

A comprehensive analysis of the current staging of the room was carried out with the cooperation of the exhibition's curator, which uncovered several negative aspects, such as the lighting, the display criteria, and the reflection effects related to the glass shelves and the mirror backdrop.

The analysis of the current display was a starting point for proposing alternative design concepts. After a brainstorming session involving all the students and a further stage of individual work, two designs were proposed, differing from each other in terms of space and general layout. The seismic safety of the display was checked at the end, and several possible interventions aimed at increasing the seismic safety of the collections, compatible to the proposed displays, were identified.

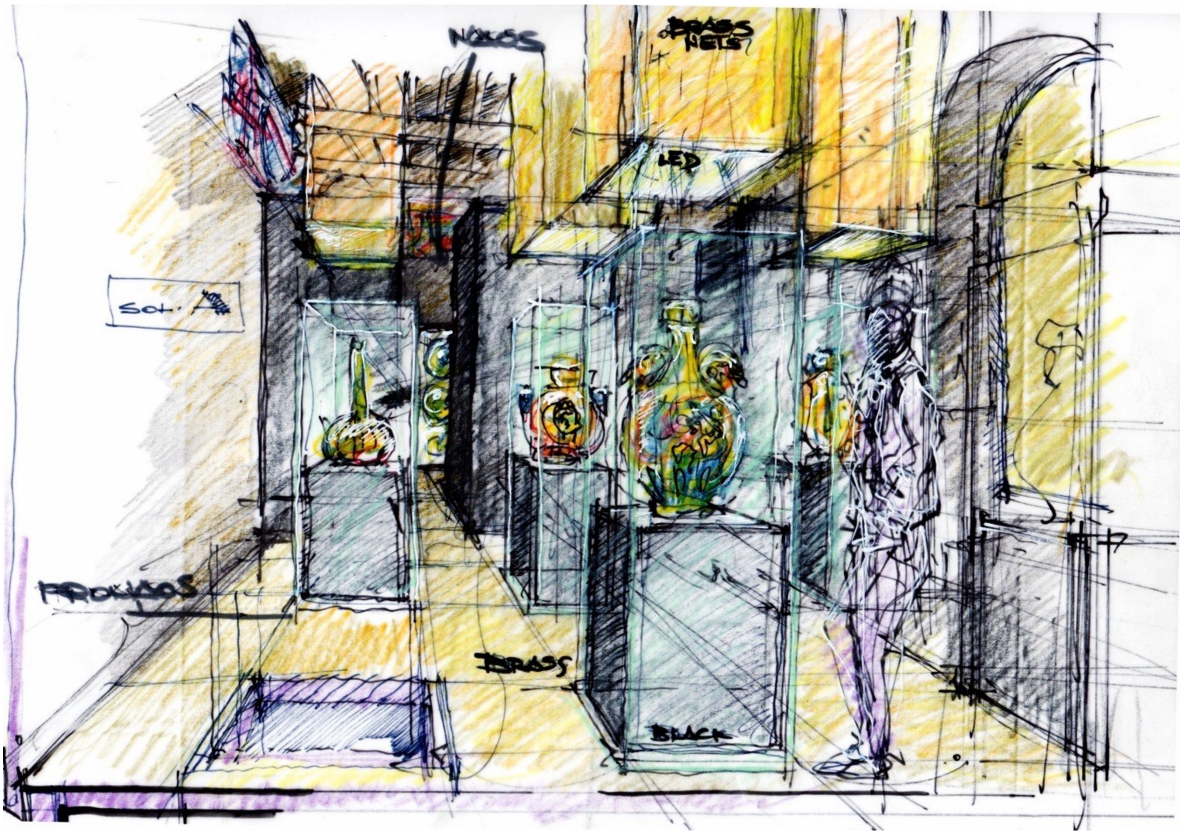



*Fig. 7. Draft of the first proposed layout (© authors).*

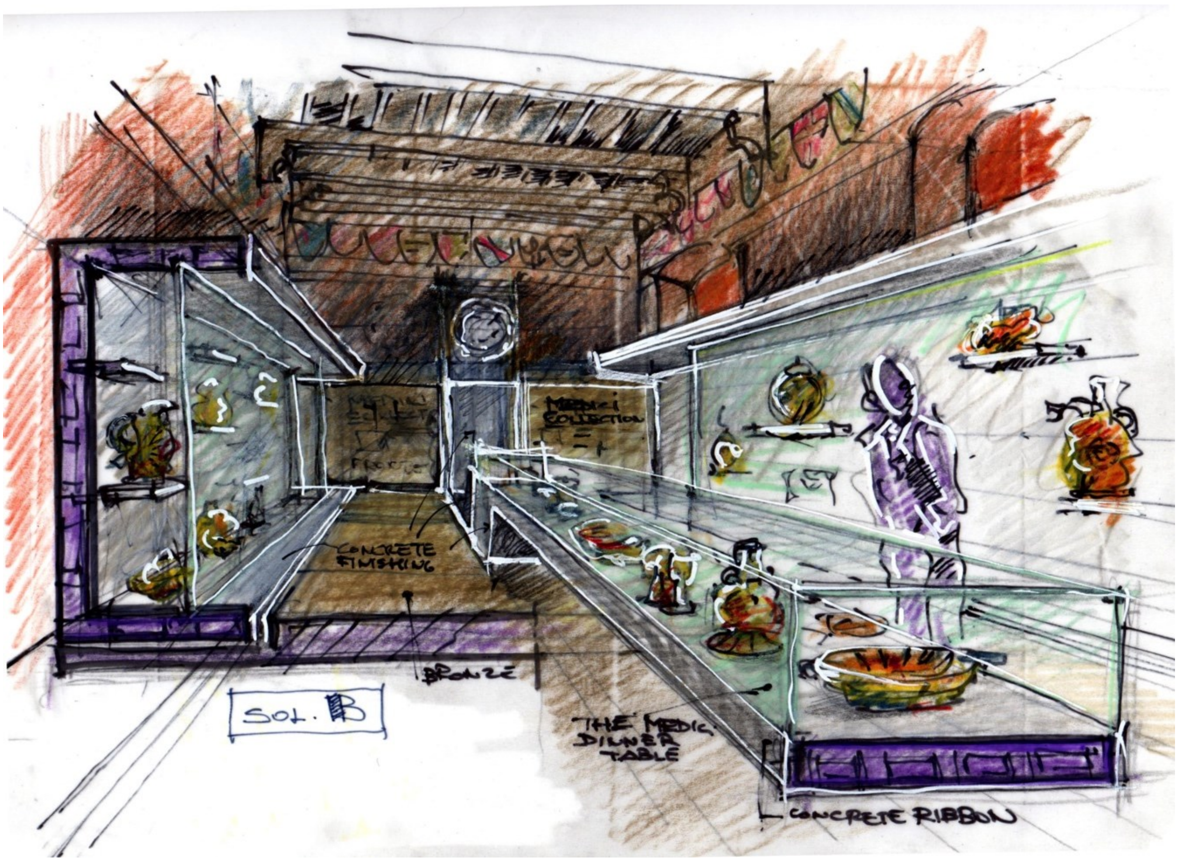



*Fig. 8. Draft of the second proposed layout (© authors).*

The proposed experience should be considered as the first step of a multiple years' activity. After the work carried out at a preliminary level, the next year's phase should involve prototyping a part of the proposed design to test various aspects of the staging. This activity should be carried out with the support of the Architettura e Autocostruzione Laboratory (Capestro and Zaffi, 2018), an equipped space of the Architecture Department of the University of Florence, where the students themselves could produce some components.

In this first phase, the didactic activity gave the students the opportunity to experience, through a holistic approach, the complexity of a strategic and important theme such as the design of an art collection exhibition and solve the main issues. The final proposals are didactic products, but they are a proof of the awareness achieved by the students during this activity.

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# Structural analysis and evaluation of interventions for the protection of the Resurrection of Christ by Piero della Francesca mural painting at Sansepolcro[1]

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***Keywords:*** *Resurrection of Christ—Piero della Francesca—Sansepolcro—Seismic hazard—FEM*

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## Introduction

The Resurrection of Christ mural painting (Fig. 1) was realized by Piero della Francesca about 1460 on a brick wall (15 cm thick) placed in a different place as it is today. Shortly later, the painting was moved by means of a transport to solid-wall and placed against a pre-existing wall (60 cm thick), where it is today, erecting against this wall a counter wall (15 cm thick) where the mural painting wall-panel (225 × 200 cm) had been inserted. The existing wall is not jointed to the two main lateral walls. The most complete reconstruction of the historical events of the palace is written by C. Blasi (2004), reported here with the additions deriving from A. Cecchi (2012) and A. Borri (2015).

The building that was originally the Conservatori Palace and holds the mural painting, today is incorporated in the aggregate building of the Museo Civico di Sansepolcro. The building was built in the XIVth century as a large hall for public assemblies. In the XVth century the hall was divided into the two current smaller halls with the construction of wall in false. This wall had a fireplace and a chimney in the hall opposite the mural painting one. Below this wall the basement had been reinforced with an arch. In 1474 the original wooden ceiling was replaced with barrel vaults and lunettes and the fireplace was closed with a wall.

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*Fig. 1. The Resurrection of Christ by Piero della Francesca in the Sansepolcro museum (courtesy by the Sansepolcro Municipality) and a view of the BIM model (© authors).*

A little bit later, on the side opposite the fireplace, the Resurrection of Christ mural painting was placed by means of transport to solid-wall. For this purpose, against the pre-existing wall (60 cm thick) was erected a counter wall (15 cm thick) where the mural painting wall-panel (225 × 200 cm) had been inserted.

The building currently consists of three levels with a rectangular plan (44 × 9 m) and height of about 14 m. A central wall divides the volume into two almost symmetrical parts of about 22 × 9 m. The basement floor overlooks Fiorenzuola street at the south and is buried on the north side. The two halls are located on the first floor. In the attic floor the extrados of the vaults of the two lower halls are visible and the floor built in 1939 on the vault of the hall with the mural painting. The ground floor is covered by cross vaults in bricks (two heads); brick barrel vaults (a head) cover the second floor. The rebuilt vaults in the hall of the mural painting are hung on a floor with tables on metal beams, except for the part near the building's façade. The current roof was built in 1967 with trusses formed by "Varese" joists in prefabricated reinforced concrete and steel chains; replacement of the filling of the vaults with lightened clay and insertion of chains after the earthquake in Umbria in 1997. In 2017, a consolidation of the structures was carried out by positioning structural reinforcements above the vaults or on the floor of the attic.

The Sansepolcro area presents a strong historical seismicity (six earthquakes > VII MCS in the last 1000 years), which caused several damages to buildings. Moreover, in WWII the Nazi retiring blasted some edifices causing local vertical rebound up to 1g. In the last years, the Sansepolcro Municipality supported a series of studies regarding the structural behaviour of the hall where the Resurrection of Christ is, in order to safeguard it from seismic hazard. These studies are also preparatory for the intervention of restoration of the mural painting executed in the years 2016–2018 by the Opificio delle Pietre Dure.

## Cognitive framework

To achieve the objectives of the research the Department of Earth Sciences has carried out the surveys, in line with the MIBACT 2011 Guidelines (point 4.1.6) and in full cooperation with the Museum Opificio delle Pietre Dure and local Superintendence. The surveys conducted concerned the type and characteristics of the walls that make up the museum hall and the wall where the wall painting is placed. The history of the building and its current assembly was studied, the fissure crack network mapped, and a series of non-destructive tests (NDT) were performed: GPR, sonic and ultrasonic, DAC-Tests, microendoscopy and thermal. The dynamic behaviour of the hall has been defined through a FEM analysis and has been correlated with the results of the 5-year work monitoring system.

The cognitive studies allowed defining the masonries structures: that of the hall, 110 cm thick, was erected in mortared sandstone slabs, that of the intermediate wall (60 cm thick) supporting the mural painting wall panel in mortared stone cobbles and bricks; these two masonries are not well linked one to the other. The counter wall (15 cm thick) within which the mural panel is inserted, is in mortared bricks and small sandstone cobbles.

The use of the Abacus provided by the Tuscan Region (SSRT 2003) and the Circular 617/2009 ex NTC2008/2018 Ministry Infrastructure and Transport allowed us to attribute the reference values of the physical-mechanical properties of these historical masonries (Table 1).

| Masonry type | $f_m$ | $\tau_m$ | E | G | w |
|---|---|---|---|---|---|
| | $N/cm^2$ | $N/cm^2$ | $N/mm^2$ | $N/mm^2$ | $kN/m^3$ |
| Masonry in stone cobble and slabs irregularly placed | 150 | 2.5 | 800 | 300 | 19 |

*Table 1. Physical-mechanical properties of the studied masonries.*

## Structural analysis and an intervention proposal

The target of our structural analysis was to identify the first proper movements that can affect the Resurrection of Christ wall panel in the event of an earthquake. For achieving this goal, a linear elastic analysis was carried out.

The target of our analysis were the first small movements that can damage the mural painting and we are not interested in the further development of the crack pattern. Therefore, it is correct to develop a linear elastic dynamic analysis.

The analysis had been developed onto a 3D FEM of the building in an elastic and isotropic continuum using the software SAP2000 (®Computers and Structures, Inc.). For correctly simulating the package of the wall supporting the mural painting wall-panel, the intermediate wall had been modelled by using “shell” and “layered” elements.

The first movement has oscillatory main modal forms of the whole building along the short sides; for the intermediate wall supporting the mural painting wall-panel the movement results oscillatory in the plane of the wall (Fig. 2).

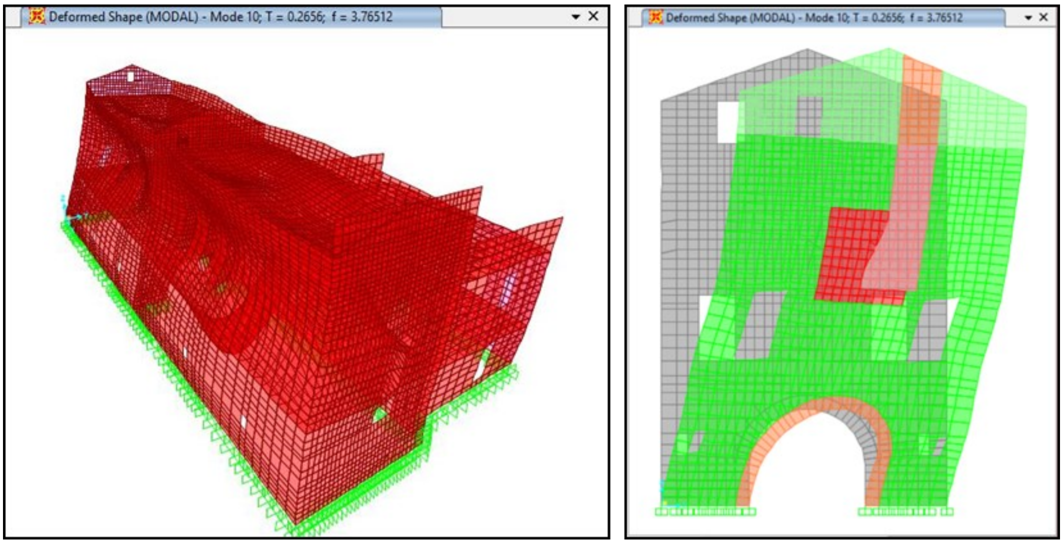


*Fig. 2. First modal form for the whole structure and for the intermediate wall with the wall panel (© authors).*

The FEM simulation fully describes the first movements in the event of a remote earthquake, which will be in the order of 0.01 mm, 0.2 mm and oscillatory in the plane of the intermediate wall containing the wall-panel. These movements and their entity is fully compatible with the fissure pattern and the five-year monitoring results.

This dynamic behaviour, the soft connections and cracking patterns can explain why the Piero della Francesca's Resurrection of Christ mural painting remained unharmed, despite the numerous seismic events that occurred in the area in the past centuries.

The position of the Resurrection appears optimal, placed in the portion of structure less stressed in the event of an earthquake. However, we can consider a minimal intervention that involves the arrangement of supports aimed at retaining the painting without hindering the current structural behavior. In this way the possibility of a tilting of the painting panel out of the plane of the masonry is avoided that contains.

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# Round Table:
# Citizen Participation in archaeology in the digital era

Elisabeth MONAMY | Sigrid PETER

## Citizen Participation in archaeology in the digital era

Chairs:
Elisabeth MONAMY, Archeomuse, Austria & Universität Bern, Switzerland
Sigrid PETER, Association for preservation and research of castle „Ried am Riederberg", Austria

***Keywords:*** *archaeology—citizen participation—cooperation—public*

Everyone is interested in archaeology. And yet the image of the archaeologists and their work is rather modest. The profession of archaeologist stands for breadless work and the archaeologists themselves as untouchable. Their work remains largely closed to a broad public and the rest of the population. Many archaeologists do not even want to work with non-specialists for fear to answer banal questions and losing time with training. These are prejudices that make communication and cooperation between archaeologists and laymen difficult or even impossible.

The aim of this round table was to bring together archaeologists and laypeople in order to enable a better civic participation in archaeology. Who got what role and who could take on what task? The round table showed also the advantages and disadvantages of the cooperation between archaeologists or specialists and newcomers or laymen who only want to go once on a "treasure hunt". New technologies (blogs, vlogs, apps, etc.) were a starting point where amateurs can contribute their questions and knowledge. Could VR and AR be as attractive to laypeople as them starting to care about heritage? How can the interaction between scientists and amateurs lead to new citizen scientist projects? And how could their results be integrated in Open Access scientific publications?

We invited professionals and amateurs to participate in the discussion. The Round Table consisted of many different short impulse lectures (5–10 min) and a discussion in which all participants and listeners were invited to actively participate.

This Round Table was the place for discussing general issues, rules, and lessons learned as well as to allow new approaches and ideas about involving the public.

# Boosting public participation in archaeology using test-pit excavations in Austria

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***Keywords:*** *public participation—community archaeology—test-pits*

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## Situation in Austria

Public participation in archaeology and citizen science are topics gaining increased attention in recent years – also in Austria. Despite ratification of FARO convention (Hebert et al., 2019) by the Austrian government in 2015 not much changed for the public. Only a very limited number of archaeological projects are offering participation in fieldwork and research for citizens. As a direct result of FARO subscription ArchaeoPublica, an organisation for public participation in archaeology (ArchaeoPublica, 2019), was founded by professional archaeologists and members of the public in 2015. Other kinds of projects are for instance senior courses from Urban Archaeology Vienna targeting archaeological finds processing and recording and educational activities for undergraduate students in schools.

These few possibilities for direct participation are not a result of lacking interest of the public as the results of a recent survey pointed out (Karl, 2016): About 74 % of Austrians indicate a moderate, high or very high interest in archaeology. 85 % of these show a significant interest in archaeology and 58 % would participate in actual archaeological activities. On the other hand, causes for the limited options in active participation can be found in the so-called ivory-tower-mentality and in missing or low understanding of science and research in the Austrian population (Peter, 2019).

## Community archaeology in the UK

A promising model for boosting the number of participants could be found in the well-established British community archaeology. The extensive tried and tested method of test-pit excavations applied in the research of currently occupied rural settlements offers an uncomplicated way in involving participants of any age. The idea for standardized evaluation pits arose from investigation work on medieval settlements. Previously research was focused mostly on deserted villages. But this type of settlement is quite a special one in comparison to the thousands of still occupied historic settlements today. Investigating currently occupied settlements is only possible by integrating the citizens in the research process. The active participation of the local population enables scientific researchers to enter private garden and backyards.

Test-pits are standardized 1-meter square evaluation trenches. By excavating in virtual 10 cm contexts (also known as spits) the removed soil is sieved and all finds are recorded. Dating the found pottery fragments help to document different periods of domestic activities at a particular site. By repeating this procedure many times in the surrounding occupied area, a map of settlement activities over different periods can be created. With the yielded information it is possible to postulate new theories about the impact of influences on the historic population, like epidemics or natural disasters, not only for a single settlement but also for vast regions.

In a short time, citizens and students are able to learn a lot about research work in archaeology. Normally a test-pit campaign can be dug in two days, preferable on Weekends. The excavation process of every pit is stopped either by reaching a depth of one meter, reaching natural ground, reaching a complex archaeological feature or when the available time is running short. Eventually all opened trenches are backfilled, and the removed turf is put back in place.

Test-pit excavation projects are an important part of public participation in archaeology in the United Kingdom (Lewis, 2014). In June 2003 volunteers dug one thousand test-pits for Time Team's Big Dig program on Channel 4. Since 2005 the University of Cambridge involved about several thousand students and local residents in east England digging more than 2000 test-pits in ten years. In 2019 the EU-funded Community Archaeology in Rural Environments – Meeting Social Challenges (CARE-MSoC) project started test-pit excavations in four European countries, involving the United Kingdom, Netherlands, Czech Republic and Poland (Lewis et al., 2018).

*Fig. 1. Work at Riseley 2014 Higher Education Field Academy (HEFA). Photo by Access Cambridge Archaeology (https://www.access.arch.cam.ac.uk/news/riseley-2014-higher-education-field-academy-hefa) is licensed under CC BY-NC-SA 4.0 (https://creativecommons.org/licenses/by-nc-sa/4.0/).*

The educational background of projects like the Higher Educational Field Academy (HEFA) or the Independent Learning Archaeology Field School (ILAFS) led by University of Cambridge focuses in particular on regions with low educational levels. Archaeology functions as a low-threshold instrument to give participants an insight into scientific research work and to encourage students to get interested in studying on a university after secondary school.

## Getting started in Austria

A possible way to get started with projects of this kind in Austria would be to involve university and academic institutions and encourage them to set up independent research projects focusing on test-pit campaigns. Another way would be to join an EU-funded scheme like CARE-MSoC. A funded university project could cover a region of up to several boroughs and involve up to thousand people of many local communities. On the other side municipalities, museums or public associations could start local research projects to cover few settlements. One or more municipalities (up to a borough) could involve dozens or up to hundred people of local communities. A range of such small-scale projects could join up with an umbrella organization to share scientific data and social experiences creating a national or international network of community archaeology projects. Whatever type of project can be established, the number of people and students that can be reached is a promising motivation to at least give it a try.

*Fig. 2. Work at Long Melford 2014 Higher Education Field Academy (HEFA). Photo by Access Cambridge Archaeology (https://www.access.arch.cam.ac.uk/news/long-melford-2014-higher-education-field-academy-hefa) is licensed under CC BY-NC-SA 4.0 (https://creativecommons.org/licenses/by-nc-sa/4.0/).*

## Social benefits

Last but not least, there are a number of social benefits that affect community test-pit projects: different kinds of people have been getting together in local communities, working together and having a good time. Children, students and non-academics get in touch with scientific research work and gain experiences in teamwork. They are taking responsibility by executing all stages of required work: first they measure out and mark the test-pit square followed by careful removal of the turf. The next step includes the excavation work and the documentation of every context on record sheets as well as washing and sorting finds. At last, they backfill the trench and carefully put back the turf on the ground to restore the lawn.

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# Citizen participation which integrates technologies engaging with archaeology related issues

## Use of digital technologies in protest at the British Museum

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***Keywords:*** *digital ethics—museum—creative protest—citizen participation*

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### Introduction

Anti oil sponsorship protest group BP or not BP organises protests in the British Museum, London, against oil company BP's sponsorship of exhibitions. They believe in alternative funding since they perceive that sponsorship by BP of arts and heritage projects distracts from climate change caused by the use of fossil fuels. It can be judged that during the protests the museum is a platform for free speech, in an atmosphere where the protests are allowed. Protests have featured creativity inspired by issues related to topics such as archaeology, and are designed to raise public awareness, encouraging citizen participation. Use of digital technologies: BP or not BP post the films documenting the protests on their website, and encourage people to take part in future protests. They also use social media site Facebook to raise awareness of their campaigns, and to raise awareness of other protests and media developments, relating to ethics and arts sponsorship. The protests feature interesting performances which makes them an exciting subject for photographers and journalists. The protests are usually covered by printed and digital media. People taking part and observing the protests also take photos using digital cameras and share these photos on social media. This can be viewed as an aspect of the recent phenomenon of engagement with museums and collections through social media, part of the integration of digital technologies into contemporary culture. Through the dissemination of information through technology, a story of the protests is built up outside the museum and beyond the protest which documents multiple viewpoints, preserving documentation of the protest on the internet, which can be viewed as a public archive.

This paper will present case studies exploring the integration of digital technology into different protests.

Case studies:

1. A BP sponsored exhibition in the BM where an environmental issue inspired protest relating to the 2016 Sunken Cities: Egypt's Lost Worlds exhibition. This major exhibition was on the discovery of

two lost Egyptian cities under the Mediterranean Sea, the museums' first large scale exhibition of underwater discoveries (British Museum, 2015). Critics of oil sponsorship of the exhibition argued that 'much of Egypt's coast is beginning to be seriously affected by sea level rise', relating this to the activities of BP and the use of fossil fuel (Rowell, 2016).

Protests in 2016 by BP or not BP in the BM against BP sponsorship of the exhibition was inspired by its' themes. Including protestors drenching themselves in water, highlighting the view that global warming causing rising sea levels will drown major cities in future years, and that BP contribute to this with their activities involving extraction of fossil fuels. BP or not BP 'flood[ed] the BM with a 200 strong splash mob featuring musical mermaids, oily pirates and a 40 foot kraken' sea creature similar to an octopus. Turning things back on BP in the protest a protester claimed that the splash mob aimed to ´flood` BP out of the museum. Citizen participation with technologies included: films capturing the creativity and vibrancy of the protests, posted on the bp or not bp website, documenting citizen observation and participation. This included footage of participants texting on phones, and photographers (bpornotbp, 2016). An *Evening Standard* article reported a protest and development of the story on social media including a Twitter feed of photos within the article (Collier, 2016).

2. In February 2019, BP or not BP staged a protest in the British Museum about ethics relating to the temporary exhibition I am Ashurbanipal king of the world, king of Assyria November 2018-February 2019 (British Museum, 2018). The protest was against oil sponsorship and engaged with ethics surrounding objects in the exhibition perceived as ´looted` from Iraq (bpornotbp, 2019). The protest also had an anti war sentiment. A film made by BP or not BP documented the protest, the main focus of the protest was 'a "living artwork" that circled the entire Great Court', this was 200 m long. The protest marked the 16 year anniversary of the 'demonstrations against the invasion of Iraq' (bpornotbp, 2019).

The film documented the use of digital technologies by citizens present at the protest: use of digital cameras, phones etc. Technologies were also used by leaders in the protest, for instance use of microphones etc.  This was the most prominent use of technologies I have yet seen at a protest.

3. An article on art.net in June 2019, in anticipation of an exhibition scheduled for Autumn 2019 at the British Museum, about the Trojan war shared the views of anti oil protest groups about BP sponsorship of the exhibition. This article was on the internet and an example of anticipation of protest before the opening of the exhibition, through digital media, since the sponsorship has already been criticised. The exhibition will include loans from museums in Berlin, focussing on German Heinrich Schliemann's 19th Century excavations (Pes, 2019).

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# Who needs citizen participation?

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***Keywords:*** *citizen participation—archaeology—treasure hunt—lay people*

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In recent years it has happened quite often that laymen are not only interested in history and archaeology, learning about new discoveries and new theories about lost civilisations, but also seek direct contact with archaeologists and their work.  This may be very popular with the general public and in different media, but how do archaeologists react? How can archaeologists prepare themselves for the fact that all at once not only colleagues and students dig along but also laymen who have no idea of the work and the subject? Or maybe they have seen a documentary on TV or online and believe they now know enough to participate in a dig. Prejudices from both sides, laymen are just "treasure hunters" and archaeologists are arrogant scientists who do not want to share their knowledge, make the comprehension for the other quite difficult.

In addition to the extra preparations that are now necessary for the archaeologist and thus take up more precious time, the excavation management on site must take the time during the excavation to familiarize themselves with laymen. This first and most important fact is the factor time. Time is something archaeologists do not have! Time will be needed for organisational purposes or bureaucracy. And later on site archaeologists have to take the time to teach during a "crash course" the archaeological methods and excavation technologies to laypeople. Is it at all possible to acquire in a very short time (excavation can take from some weeks up to months) the knowledge, which specialists have laboriously acquired during many years of experience and study? It is not only about the excavations methods, how to dig and handle the finds on site, but also to understand their meanings in a context and register all the information required from a database. An object alone provides only a fraction of information if it is not considered in its surrounding. Especially during rescue excavations, one has hardly time to explain what has to be done when digger and construction worker breathe down archaeologist's necks. Recently, there have been companies that have specialized in excavation participations for laymen. They introduce the interested parties to the methods and provide the necessary background knowledge. This can be a great relief for excavation supervisors, who must invest less time for laymen. Laymen are now looked after by archaeologists who support them in every respect during the excavation. There is also a new proficiency pass which enables to evaluate one's competences in digging.

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*Fig. 1. (© E. Monamy)*

Most of the time laymen interested in archaeology and especially in excavation or participating in any other way are not young people. They are people who have their (well paid) jobs and want to live their passion for history and archaeology during their holidays and free moments. These people have time and already a lot of life experience. They heard and read a lot of popular knowledge and believe to know everything about one subject. Accordingly, it can happen that they will not accept a younger archaeologist in charge who will tell them how to work. The author's own experience shows that elderly people have difficulties accepting younger specialists or experts. They are not considered as experienced or professional enough.

Last but not least, why should laymen dig along? Can archaeologists ask a medical doctor to assist and have a look during a vital operation just because they feel like learning something new about medicine? Can archaeologist spend their holidays as a policeman chasing burglars with a gun around a town just because they saw a very fascinating documentary on TV?

What can it be that laypeople bring with them in order not to burden the work of archaeologists?

In this short impulse lecture, the author will show that citizen participation in archaeology in the digital age is not possible without reservations. These reservations are listed and explained to show that it is not as easy to imagine citizen participation in archaeology even in our digital era as many seem or would like to believe.

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# Of preserved ruins and ruined castles

## An example of public participation and monument preservation in Austria

Sigrid PETER, Verein zur Erhaltung und Erforschung der Burg am Ried am Riederberg, Austria

***Keywords:*** *Public participation—Heritage—Citizen science—Science communication—Preserved ruin*

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### "Verein zur Erhaltung und Erforschung der Burgruine Ried am Riederberg"

The "Verein zur Erhaltung und Erforschung der Burg Ried am Riederberg" (Burgried, 2019) is an unique project in Austria as a bottom-up citizen science association. It was founded in 2010 by interested citizens and has about 35 members, about ten of those are actively working at the project. The aim of the association is to preserve and do research in an old castle ruin in Lower Austria, a historical monument which is protected by Austrian law. "Burgruine Ried am Riederberg" is a medieval castle ruin with a momentous history: In the 13th century, historically noteworthy persons owned it, for example the noble house of Kuenring, an important family of ministerial officials in medieval times. The castle was probably erected in the second half of 12th century and in use until 1420.

The association is financed by contributions from members and by government subsidies. There exists a close cooperation with the Federal Monuments Office of Austria as well as with archaeologists, art historians, geologists, and educators. This wide range of participants illustrates an interdisciplinary research approach. There are two advisors from the Federal Monument Office: Mag. Dr. Martin Krenn for archaeological issues and Dipl.-Ing. DDr. Patrick Schicht for questions of preservation of ruins.

For the association, the main focus lies in three areas: First of all, there is a strong focus on interdisciplinary research, which is starting with citizens. They are posing research questions and attempt to get answers to them, working together with academics. Another focus is on the preservation of the object. Members work together with a curator of monuments and try out old and new technologies to achieve the best preservation of the object. Last but not least, the association imparts newly acquired insights to the common populace by organizing exhibitions or having "open dig"-days for local people.

*Fig. 1. Castle ruin Ried am Riederberg (© Verein zur Erhaltung und Erforschung der Burg Ried am Riederberg).*

**About Research, Heritage, Education and cooperation with academics**

Supervised by professional archaeologists, members of the association conduct archaeological actions every year. Those actions include all parts of an usual excavation, including digging trenches, documenting finds, sorting and washing them and working with GIS. In 2019, a German version of the British Archaeology Skills Passport was published and will be put to use during the next campaign. The experience by working together is very valuable: If an academic is open to working with citizens, the cooperation achieves very good results and a wide range of insights, eliminating a lot of misconceptions on both sides. An open communication is extremely helpful for better understanding our heritage.

In ruin preservation was an intensive examination of the right way—which includes all kinds of mistakes and errors people are able to do and the beginning. 2010–2014 there were some discrepancies about the "right" way of preservation and the "right" material. In 2014 the association got in touch with Robert Wacha (†) and Hannes Weissenbach at the "Informations- und Weiterbildungszentrum Baudenkmalpflege – Kartause Mauerbach" (Kartause Mauerbach, 2019). Both explained the right usage of lime mortar, ruin preservation and pointed some members of the association towards the right direction of restauration works to preserve the appearance of the ruin. They also told them to establish a long-range monitoring for ascertainment of damage. Another point of heritage conservation is thesite care around the ruin. Since 2019 there is also a good contact with the initiators of the Interreg-project "Bürger retten Burgen".


*Fig. 2. Members on an excavation (© Verein zur Erhaltung und Erforschung der Burg Ried am Riederberg).*

Last but not least there is also an educational focus: In the last years there were some open dig days during the excavations. In some years the association organized activities for children at the summer holidays. In 2017 was a museum exhibition at "Wienerwaldmuseum Eichgraben" (Wienerwald-museum, 2019) about "Die Burg Ried am Riederberg und die Kuenringer im Wienerwald" ("Ried Castle at the Riederberg and the Kuenringer in the Vienna Woods") (Peter, 2019). Last year was the "Tag der Archäologie" ("Archaeology Day") in St. Pölten/Lower Austria where members of the association gave visitors information about the project and the work. There are talks on expert conferences and in the near local area for the population about the project as well.

**Workflow with troubles: Challenges and benefits**

By and large the project is working and after about ten years it needs to be said that there were some internal troubles at the beginning. After establishing the association, the members formed two groups of interests, which had different opinions on the heritage management of the castle. On one side, some members wanted to excavate the ruin, on the other side some of them wanted to preserve the existent remains. Another question brought conflicts between the members: Is a heritage monument a kind of cultural heritage and research project or can it be (also) a playground? The last but most important reason for differences were discussions about long-range monitoring versus a fast renovation because of panic? After all, today the object is preserved, there is also a well-established monitoring and it is seen as cultural heritage monument and as a research project.

*Fig. 3. Assembling of pottery fragments (© Verein zur Erhaltung und Erforschung der Burg Ried am Riederberg).*

Another challenge is the language barrier between academics and commons. Professionals are prone to a high language level which is often not easily understood emby the public. This produces misunderstandings. Moreover, science and heritage are two very complex domains which are partially hardly to understand for non-academics, so sometimes it is difficult to reach the public. On the other side common people have less appreciation for archaeology and heritage. Finally, there are a lot of different expectations between the local population and researchers. Members of the association are often frown by scientists, although they work on a high scientific level and make a point doing of a high-quality standard.

Beside some challenges there are also a lot of benefits: Citizens have the possibility to be part of an innovative project. They are able to work side by side with scientists and get involved of interdisciplinary research approach. As public they participate on the whole research process and get know-how in archaeology, heritage and ruin preservation. Last but not least there is also a lot of fun and extensive socialising by working together.

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# Beacons of the Past

## Citizen Science and Community Engagement in the Chilterns

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## The Project

The Chilterns Conservation Board (CCB) is delivering an exciting project which will engage and inspire communities to discover, conserve, and enjoy the Chilterns' Iron Age hillforts and their prehistoric chalk landscapes. Located in south-eastern Britain (Fig. 1), the Chilterns region has the tenth largest collection of hillforts in the UK/Ireland (Maddison, 2019), yet many are poorly preserved, and little is known about them. Supported and part-funded by the National Lottery Heritage Fund, from now until October 2021, the *Beacons of the Past* (BotP) will provide a real focus for community and public involvement through remote sensing and survey, practical excavation, and research, as well as a programme of events and educational activities. The project will help people connect with the prehistory of the Chilterns and encourage them to visit and enjoy the hillforts and their landscapes through practical research and conservation skills. As a result, Chilterns hillforts will be better understood, in better condition, and more accessible.

An exciting first step is a LiDAR survey of the Chilterns—the first of its kind in this area. Environment Agency (EA) LiDAR data has wide, and growing coverage of the UK. In the Chilterns, large areas are still yet to be surveyed by EA, with completion planned by 2021. The EA data which does exist for the region has often been flown at 1 m resolution. At this resolution, many archaeological features are not identifiable. This is particularly exacerbated under tree cover, where ground point densities are inevitably lower than for open ground.

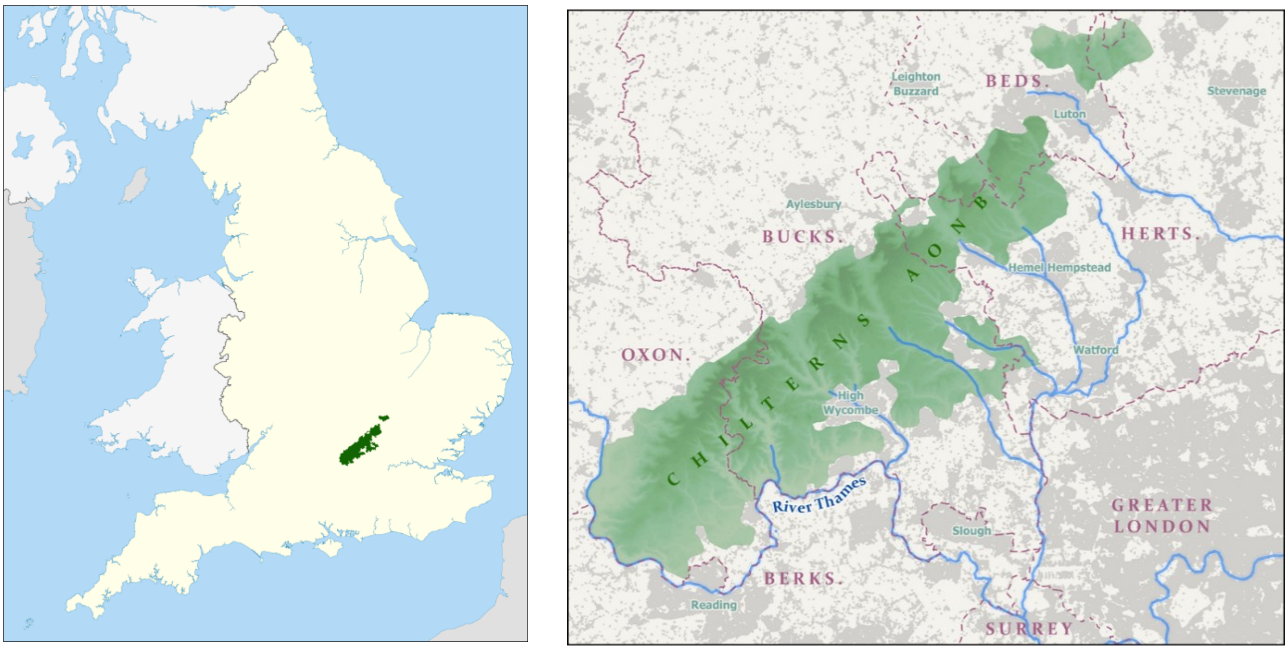
A bespoke LiDAR dataset was therefore viewed as being of great benefit for enriching the understanding of this landscape, and through funding from the National Lottery Heritage Fund and other partners, the largest bespoke high-resolution archaeological LiDAR survey yet undertaken in the UK was commissioned. Encompassing 1400 km$^2$ (Fig. 1) and flown at a minimum resolution of 16ppm, extending to 27ppm in open ground, utilising the Riegl Q1560 LiDAR sensor, the survey offers not only the potential to reveal hundreds of new archaeological sites.

## Citizen Science

The project has worked to create a bespoke web-GIS and heritage asset management system, to allow ready, free, licence-less access to view data layers including several LiDAR visualisations, aerial photography, and large scale modern and historic mapping. Following on from the arguments of Duckers (2013), the project has put the task of interpreting the landscape into the hands of the public, understanding that 'experts' do not know the landscape as well as those who live in it, work in it, and in many cases have spent decades exploring it.

This approach has the benefit of assisting to interpret and map archaeology over the vast survey area. Papers by Duckers (ibid), Curley et al. (2018), and Lambers et al. (2019) have reported on the 'efficiency' of different techniques for analysts, both expert and non-expert. The BotP web portal explicitly asks its citizen users which visualisation technique they have used for recognising a feature, so a large dataset will be created showing the preference for and effectiveness of the different visualisation techniques offered to them.

A citizen science approach also allows a route to unprecedented engagement with the public. Not only is this data type relatively restricted to expert users, but geographic information systems (GIS) are also generally restricted to professional users, by both licence fees and knowledge barriers to their use. The project presents a simple, user-friendly, well-documented GIS system which allows engagement with audiences, many of whom will never have heard of LiDAR or GIS, and indeed many of whom may not otherwise have been interested in archaeology. It may also form a useful learning tool for archaeology or geography students, or professionals as Continuing Professional Development training.




*a* *b*

*Fig. 1. Location of Chilterns in the United Kingdom. a) © Natural England 2012 b) via Creative Commons (© CCB)*

## Community Engagement

A full range of activities beyond just the citizen science LiDAR transcription, including workshops, talks, activity days, and field-checking sessions, run across the AONB, opens access up to an even wider range of participants, with 1.6 million people living within 8 km of the Chilterns Area of Outstanding Natural Beauty (AONB), and the more than 50 million visits the AONB attracts every year.[1]

For those who would like to get more involved outdoors, the project offers a series of conservation events from litter picking on monument sites to 'scrub-bashing' – removing damaging and invasive vegetation from the earthworks. We have also been running training workshops in the use of Geographic Information Systems (GIS), LiDAR interpretation, and topographic survey.

As the Chilterns and its environs cover over 1000 km$^2$, the project has split the region into four zones and deliberately replicates most events at least four times to be certain there is parity across the entire area. There is an unfortunate tradition of London- and south-centric bias in engagement projects, which this approach helps to mitigate. Of course, no community archaeological project would be complete without a little digging in the dirt—there have been small scale targeted excavations led by trained professionals but open to completely inexperienced enthusiasts, who, under careful leadership and training, have successfully excavated and recorded prehistoric features relating to the hillforts.

*a* *b*

*Fig. 2. variety of training events offered by the project: a) Guided site visits, invasive scrub clearance, GIS training, and topographic survey training. b) Residents of the Chilterns AONB enjoy an array of hands-on experiences at Pop-up Prehistory events. (© CCB)*

Beyond the capital and practical works on sites, and the identification of new features and sites through LiDAR analysis, BotP is also delivering community events that promote understanding of prehistory and appreciation of prehistoric heritage resources. Both in the classroom through teacher support and resource provision, the project also hosts 'Pop-up Prehistory' events around the AONB and environs. These events are a blend of prehistoric crafting activities and living history, with hands-on learning opportunities (Fig. 2). Given the location of several large urban areas within the Chilterns, the project team has the specific aim of reaching out to and engaging with non-traditional audiences, such as the differently abled and ethnic minority communities.

[1] https://www.chilternsaonb.org/conservation-board/management-plan.html

## Conclusion

Beacons of the Past provides a real focus for community and public involvement through practical excavation and conservation work, technological and survey research, and a programme of events and educational activities.

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# Augmented Reality-based Treasure Hunts in Cultural Mediation

## How we use augmented reality to revolutionize cultural mediation in Vienna’s city centre

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### Augmented reality in cultural mediation

The personal motivation of the project members lies in the overlapping of several fields of interest: Archaeology, history, biology and especially their mediation. Being at the cutting edge is an ideal, which can be seen as a competitive advantage in the economic sector and why ArchäoNOW has established itself as a pioneer especially in Vienna.

Digital technologies are already transforming the most diverse fields. One area that is currently facing a major change is learning and knowledge transfer. Not only teaching methods are changing, but above all the methods of conveying content. The cultural sector is also particularly affected and must reorganize itself structurally and thematically in order to be able to react to the rapid pace (Pöllmann and Herrmann, 2019). The project team is convinced that the intelligent use of modern technologies in combination with new content concepts will greatly enrich the experience of cultural assets and open up new target groups.

Augmented Reality (AR) is one of the technologies that can make a decisive difference here. AR expands the real world, which is perceived by the senses, with digital elements. There are two different methods of detecting and triggering AR. One is based on the identification of the place, the other is based on the optical recognition of an object.

The fields of application are versatile and so AR also offers various possibilities in the field of cultural mediation (Pedersen et al., 2017). At present, this technology is still a few steps away from becoming standard. Nevertheless, many visitors to cultural institutions nowadays expect a lot from the digital offerings. These expectations are mainly shaped by the entertainment industry, such as games and films, but also by advertising. In competition with many other leisure activities, the aim is also to meet the wishes of a younger target audience (Pierdicca et al., 2015; Dieck and Jung, 2016; Marques, 2017; Katz, 2018).

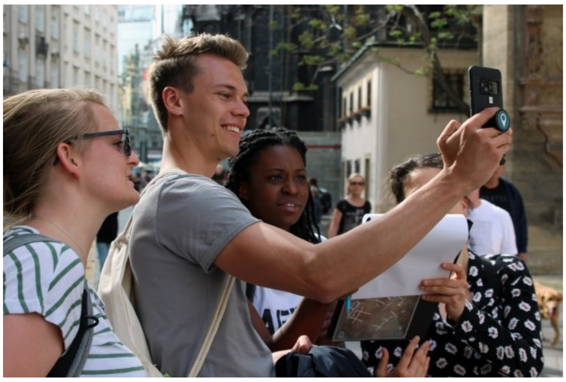

*Fig. 1. Participants of ArchäoNOW's treasure hunt, Stephansplatz Vienna (© ArchäoNOW).*

Essentially, different digital offerings suggest to the audience that an institution is not satisfied with what already exists, but rather strives to keep its finger on the pulse of the times and thus remain attractive through innovation and experimentation (Marques, 2017).

Especially in urban and public spaces, outside museums and exhibitions, cultural mediation continues to be based almost exclusively on classical methods, such as city tours. However, the quality of guided tours depends heavily on the knowledge and skills of the mediators. A disadvantage of guided tours is that they are restricted to certain time windows and the number of participants is limited (Martins, 2012). In the case of interactive cultural mediation programs, such as the ArchäoNOW treasure hunts, the above factors are excluded. The learning experience is extended in many ways by playful elements. If this form of mediation is now supplemented with AR, unprecedented possibilities open up.

*Fig. 2. Digitally reconstructed buildings of ArchäoNOW's treasure hunt, Stephansplatz Vienna (© Franco Lanfur VARS).*

On the cognitive side, the aim is to give the participants access to historical and scientific references. AR enables the persons to fully dedicate themselves to the objects (e.g. buildings and artefacts) and at the same time receive relevant visual as well as acoustic information. On the emotional side, the aim is to turn cultural mediation into an emotional, surprising, creative, entertaining and pleasurable experience and to arouse the curiosity of the participants and turn them into explorers. Furthermore, it is about the participants being able to make a personal connection to the objects to be mediated, to get involved themselves and to exchange ideas with the city as well as with the other participants and friends. That is why participative aspects are very important in mediation.

The question now arises as to which important aspects of cultural mediation can be successfully covered by AR and whether there is any evidence of this. As far as evidence is concerned, the research situation so far is rather poor. Chang et al. suggest that there has been very little research on mobile AR-guide applications (2014). In the literature, however, it has been stated by various sides that the use of AR has a positive influence on the learning experience. The authors Jung et al. (2016), Pedersen et al. (2017) and Moorhouse et al. (2017) even speak of a serious improvement. Valente Marques provides a detailed study of various aspects of the visitor experience at museums and an overview of previous studies. In her own study she states the multidimensional study of the Visitor Experience strongly supports the positive influence of AR technology over visitor satisfaction and meeting of expectations, two critical aspects of the visitor experience (Marques, 2017). Indicators emerge that AR has a positive effect.

AR thus undoubtedly has great potential to influence and transform cultural mediation in the long term. The more advanced the AR technology and the more optimized the content AR concepts are developed, the more cultural mediation can unfold. The technology can be used sensibly to make hidden things visible, such as the terracotta army (Asian Art Museum, n.d.) or the statues of the Acropolis Museum (Digital Heritage, 2013). It is particularly attractive for the team of ArchäoNOW team to create new, surprising, lively, pleasurable and entertaining approaches to versatile objects. The aim is to lower the inhibition threshold in access to AR and to appeal to younger visitor groups.

The potential is huge, and the fusion of virtual and real world will bring exciting changes in the future. Schavemaker argues that the potential for bridging the gap between the virtual and the real world in a single visual interface is a dream shared by many and thus a great stimulus for future innovation (2011). So, it remains exciting when AR will be used across the board.

## Conclusion

Finally, it must be emphasized once again that not only newly developed technologies are necessary to create an augmented reality based cultural experience. It is also the art to create concise stories, which takes up most of the time of cultural mediators. Augmented reality can be part of a new way of thinking in digital storytelling and may be expected by customers in the future. For this reason, ArchäoNOW is at the forefront of the development of these cultural programs, improving and implementing them step by step. In this way, many more stories are to be experienced interactively. This development will also find its way into tourism, says H. W. Su. He argues that on the basis of augmented reality, virtual scenic spots and cultural and creative tourism platform can efficiently promote tourism and cultural promotion, enhance tourism texture, pioneering a new era of tourism (2014).

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# Round Table:
# Visitor-Centered Intelligence for Cultural Heritage Sites

Andi SMART | Pikakshi MANCHANDA | Cristina MOSCONI

## Visitor-Centered Intelligence for Cultural Heritage Sites

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***Keywords****: Visitor Intelligence—Audience Research—Visitor Experience—Artificial Intelligence—Data Analytics*

Obtaining intelligence on visitor motivations and behaviours is an essential activity in the creation and improvement of visitor experiences. Innovative digital technologies provide affordances for the collection and analysis of visitor data that have previously not been possible. New approaches, capitalising on digital technologies, provide rich insights into visitor profiles, behaviour and experience, and help identify target audiences and inform the design of new interpretative experiences. These insights provide opportunities to compliment, and extend established methods for Audience Research.

Key themes included:

- Geospatial analysis—data collected using tracking devices, which offer insights into users' dwell times at areas of interest, and the visitor journey;
- On/off site visitor surveys can provide psychographic, socio-demographic and experience assessment of visitor segments;
- Natural Language Analysis—a growing body of data from social media platforms can be analysed using Natural Language Processing (NLP) tools in order to understand visitor sentiment;
- Speech Recognition/Analysis—speech recognition tools support the automatic transcription of oral feedback recorded at the visitor's convenience, allowing the analysis of comments;
- Visual Attention and Fixation—visitor gaze time data collected using eye tracking devices (Pupil Centred Corneal Reflection), which can provide evidence into popular site artefacts;
- Experiential Analysis—new ways of articulating the visitor experience. This may include experiential interactions, experiential outcomes and emotions.
- The aforementioned sources and methods provide an accessible way for Cultural Heritage Site managers to gain a comprehensive picture of their visitor profiles and experience, and assess which aspects require more attention.
- This session was open to papers (comparative or case-based studies) focusing on the challenges encountered in analysing visitor data in terms of lack of resources, datasets or digital privacy and data protection concerns, as well as computational approaches for capturing and analysing such data to obtain a better understanding of visitor motivations, interactions and experiences.

# Analytics in Action: Optimizing Visitor Flow through Simulation Modelling

## Using Visitor Data and Analytics to Optimize the Design and Operations of Large and Complex Venues

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***Keywords:*** *Predictive Analytics—Visitor Flow Optimization—Simulation Modelling—Visitor Experience Management*

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## Introduction

This paper discusses the use of predictive analytics to model visitor flow in large and complex venues, such as UNESCO World Heritage Sites (WHS) and museums, where visitors may use different routes to explore different exhibits and objects based on their preferences.

At times, the high number of visitors raises concern from the authorities responsible for these sites' up-keeping about the condition of the displayed art and the spaces themselves. This apprehension is well-founded. Tourists increase the amount of humidity, carbon dioxide, dust and lint at these cultural sites, which in turn effects the conservation of these spaces. Perhaps even more harmful is physical damage inflicted, usually in and around visitor entrance/exit points of the sites. WHS are great examples of the necessity of implementing visitor flow optimization at cultural sites, because they often attempt to fit millions of visitors into small, "must-see" venues. To complicate matters, governments and travel industries often wish to increase visitor numbers at these sites in order to facilitate economic growth in the tourism industry, while local communities may have different ideas about the "desirable" amount of tourists. So, while the success of these sites depends on perfect execution of conservation projects and collaborations between conservation groups and government institutions, predicting visitor flow and its optimization are key factors in these processes as well.

But visitor flow optimization is more than simply organizing lines in and out of sites. It is developing and testing multiple visitor flow optimization strategies that take into account visitor arrival volume forecasting, determining sites' "carrying plan", and peak demand management, among other factors.

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In the rest of this paper, the use of analytics in the form of statistical and simulation models for the development and testing of these strategies will be explored.

A simulation model is a digital representation of a venue with all its elements: The salient characteristics of the venue, its architecture, visitors, and services offered to the visitors. A properly developed simulation model mimics the real site in compressed time and can accurately predict the operational characteristics pertinent to visitors' experience. It also allows to test various scenarios and what might happen in years to come. Since it takes only a few minutes to simulate each scenario, valuable insights can be gained by experimenting with multiple "what…if" assumptions.

Using the following case study, the use of analytics and simulation modelling to optimize visitor flow will be explained.

## MOGAO GROTTOES – DUNHUANG, CHINA CASE STUDY: Simulation Modelling in Action

The Mogao Grottoes, located near the city of Dunhuang in the Gansu province of China, consist of almost 500 "cave temples" (grottoes) that contain the largest repository of ancient Buddhist wall paintings and sculpture in China, created between the $4^{th}$ and the $14^{th}$ centuries. In 1987, the site, which was managed by the Dunhuang Research Academy, became one of the first cultural-historical attractions in China to be listed by UNESCO as a World Heritage Site.

Managing the visitor experience at many Cultural and Natural Heritage sites is complicated by the dynamic environmental conditions within which they operate. At the Mogao Grottoes, decades of conservation research have been utilized to determine what combination of environmental factors (e.g. carbon dioxide levels, air exchange rates, air temperature, relative humidity, cave wall salt content, etc.) and visitor factors (e.g. tour group size, cave visit time, number of tours per day, etc.) are acceptable in providing a high-quality visitor experience, while ensuring that the cave artwork is protected from further damage. As the relationships between these factors are not obvious, a tool was needed to account for them in order to derive a daily visitor carrying capacity of the Grotto Zone that would ensure that the cave walls were protected.

At the time, the Dunhuang Academy was planning to construct a new Visitor Center off-site that would serve as an introductory experience prior to visiting the caves, provide for a buffer to be able to turn away visitors on days when demand exceeded capacity and enable the site to support higher visitor volumes. A separate challenge was to help the Academy correctly determine the ideal size of the Center to ensure sufficient capacity in key facility areas (parking, ticket windows, theatres, lobby space, etc.) and critical service operations (shuttles, restaurants, retail shops, etc.) to provide a good overall visitor experience.

In collaboration with the Dunhuang Academy and the Getty Conservation Institute, Kiran Consulting Group developed a capacity management planning tool to assist managers in managing the scheduling of the cave tours. This maximized the daily visitor volume while ensuring that the cave walls were not impacted by adverse environmental conditions.

Various statistical analysis tools and data analytics were used in developing the capacity management planning tool. In addition, a visitor flow simulation model that optimized the sizing of key program elements of the planned Visitor Center was developed. These two efforts were combined to comprise the first phase of the project.

The second phase involved developing a separate and detailed visitor flow simulation model of the Grotto Zone, enhancing the capacity management planning tool and integrating all of the models and tools into one system, called the Dunhuang Academy Visitor Management System (DAVMS).

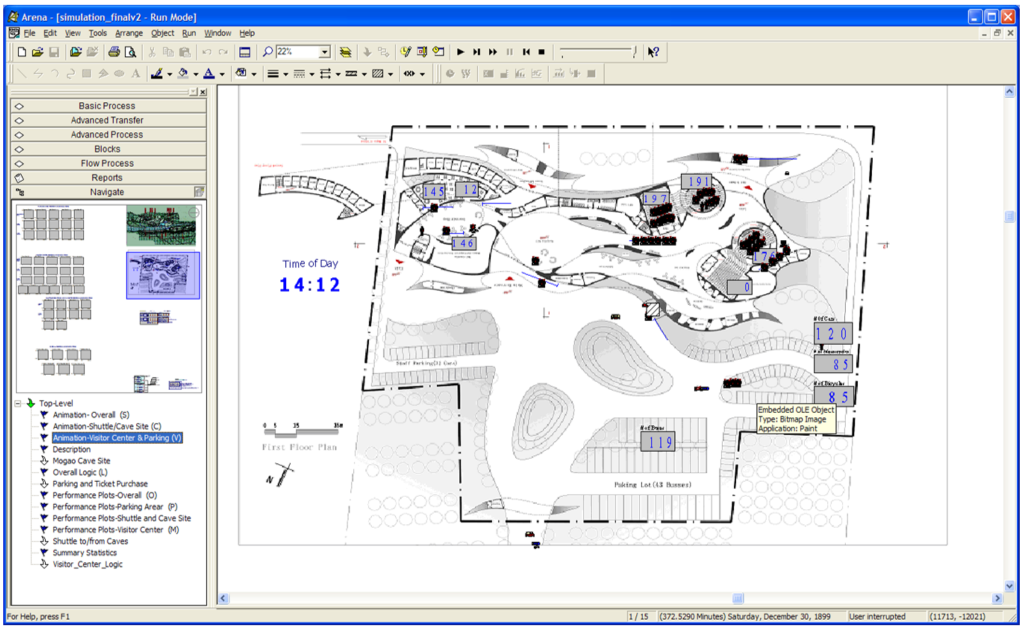


*Fig. 1. A Simulation Model of Mogao Caves Visitor Center (© authors)*

The simulation models enabled various scenarios to be run by allowing changes to be made to variable input parameters (e.g. acceptable wait time, attendance, staffing, transaction times, etc.) and also displayed visual animation of the visitor flows. A dashboard was created in the model that gave management an overall snapshot of the operating efficiency and performance of the Visitor Center and Grotto Zone. After the models were built, "what-if" scenarios were reviewed to determine the most feasible course to optimize the facility operations and resource requirements. The model also provided the functionality to vary the visitor arrival pattern, arrival modes, capacity constraints, and resource allocations.

The DAVMS system has enabled the Dunhuang Academy to proactively plan for a variety of visitor volume and environmental conditions, and determine the maximum daily visitor carrying capacity that will not cause further damage to the cave walls. In addition, the system provides managers with an operational tool to modify existing cave tours or develop new tours should environment conditions dictate that certain caves need to be "rested" in order to prevent potential damage. Finally, the system was designed to be flexible, so that as additional data and research results became available, the system could be easily updated with the latest available data.

The simulation model also used an optimized "Carrying Plan", an answer to a frequently asked question by the authorities: The maximum number of satisfied visitors that the site can accommodate without further damaging the site.

Using the developed simulation models it is found out that the Mogao Grottoes can carry up to 3,000 visitors per day when all the "must-see" caves are included in the tours. However, it's carrying capacity can increase to 6,000 visitors per day by limiting visitors to 4 minutes in some of the “must-see” caves. This capacity can even go above 6,000 if some of the “must-see” caves become “optional”.

In the example above, it can be seen that the site’s carrying capacity increases and decreases according to the number of visitors who visit the “must-see” caves. Management can control carrying capacity for the whole site by simply controlling the number of visitors who see the more famous caves.

As in the case of Mogao Grottoes, instead of planning for the site’s carrying capacity, organizers should develop a “carrying plan.” This plan should specify what actions might be needed to achieve different visitation volume goals. In the case of the grottoes, limiting the visitation times for the “must-see” caves could be one strategy for a carrying plan that serves to control the high peak visitor days. This carrying plan should also include carrying capacity targets with time dependencies. For example, let’s say a carrying plan allows visitors to see all the caves when the daily visitor volume is forecasted to be less than 3,000 per day. But when the visitation volume exceeds 3,000 the plan calls for limiting access for the must-see cave access to certain ticket holders or, alternatively, letting “regular” visitors see only a subset of must-see caves, while alternating the caves for different groups. This type of strategy is essential to a carrying plan, because unless one controls the entrance into every part of a site, it is inevitable that there will be more visitors in certain areas at different times. Thus, a carrying plan must take into account the probability of having a variable number of visitors over time in a particular area.

## Conclusions

Digital simulation models can help create and implement optimal visitor flow strategies. The input data used for the simulation models is a key component of a successful model. Use of the statistical analysis and data analytics are the cornerstones of the development of these models. As heard in the case study presented, digital tools, such as digital simulation models, are the keys to protecting historical sites while maximizing the visitor experience and volumes. Furthermore, predictive analytics and modelling can keep historical sites safe for future generations, while helping with every-day operations at the site.

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# The Future of Exhibit-Evaluation is digital

## Presenting a framework of visitor studies with a special focus on tracking & timing

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### The Role of Evaluation/visitor studies for Exhibitions

Over the last 20 years, in tourism exhibitions became increasingly popular. Investments of several million Euros are no exception. What is astonishing is that despite such large sums of money, there is hardly any control of what happens to the visitor. Exhibition plans are usually not based on thorough data regarding the pre-knowledge, images, prejudices or naive notions visitors bring with them.

To support

- the quality management (educational/interpretive role; service issues),
- the marketing and
- the legitimation

of a given site, visitor studies need to be an integral part, instead of an appendix of exhibition planning, implementation and control. It is not enough to ask for zip – codes at the ticket counter, offer a guest-book, or allow university students to do an occasional, empirical study. Also, visitor studies comprise other issues than marketing research. We need to be able to show evidence of what happens to the visitor, of what he or she takes away as an emotional, cognitive, attitudinal or other outcome (Fig. 2). Simply counting heads will not do this job in the future—besides, there are quite some differences when it comes to the ways, visitor numbers are counted.

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*Fig. 1. Museums are visited by a constantly increasing number of guests each year (© Wohlers)*

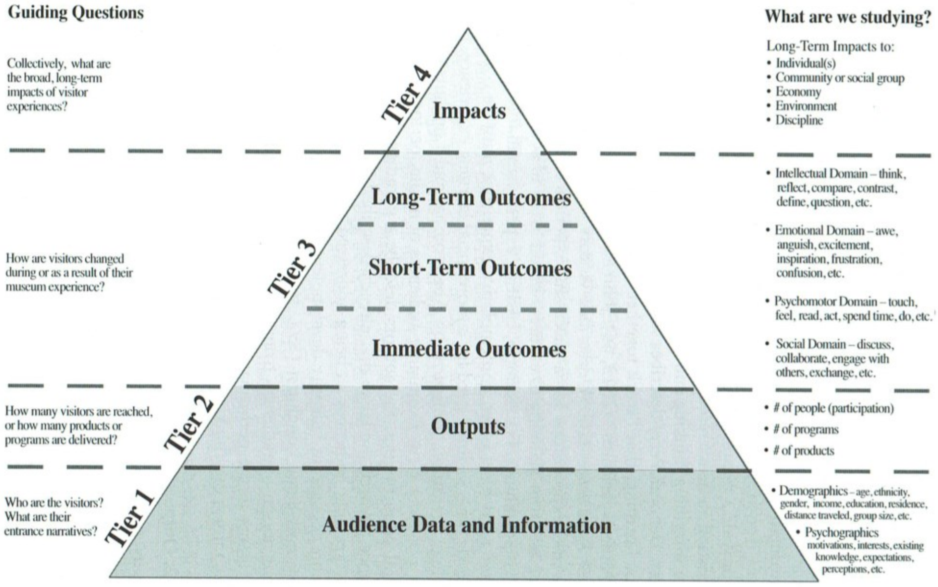


*Fig. 2. Outcomes Hierarchy (Wells, Butler, and Koke, 2013)*

## Why visitor studies do not happen

There are certainly various reasons, why there is not more evaluation, despite the benefits that we can expect to get from such regular studies. (Binks and Uzzlle, 1990) compiled these obstacles as follows:

- Lack of Interest in Evaluation on a political level
- Unprofessional evaluation techniques
- Reluctance, inactivity and low interest on the side of the staff
- Lack of clearly phrased goals
- Lack of trust and knowledge of change processes
- Lack of funding for evaluation and potential improvement

Now, what can we do about such challenges, which are not always the same for every site, but which might help to analyse a particular situation? It is suggested, that using modern digital technologies helps to reduce and partially overcome such challenges.

## Digital options for visitor studies

The advantage of using digital tools are obvious, they are simple, effective, and efficient. Nevertheless, from our experience, even interviews are rarely conducted on a regular level by the majority of sites, although there are already quite a few, sometimes even free digital interview tools available online.

For various purposes lots and lots of evaluation instruments from the field of online marketing are available for even small budgets. Conducting target group or sentiment analyses, gathering ideas for new and feedback for existing exhibitions are just a few, quick examples of what the online world can help us with. (It is astonishing that so far exhibitions are often managed with hardly any structured visitor feedback, while at the same time since years the world is in uproar because of facebook, NSA, google, etc. are collecting literally ALL data available on this planet, legally and illegally, in order to improve their systems [and influence].)

Another easily available source of data are logfile analyses from the increasingly used interactive touch-screens, -tables and other digital installations. Again it´s astonishing that such rich and easily available sources of data to evaluate and potentially improve exhibitions are not used.

While this list is not claiming to be complete, I would like to give a short review regarding a new and innovative digital instrument for the observation of exhibition visitors. While there have been various ways of approaching the evaluation concept of tracking & timing (t&t), so far there was no satisfying technique (table 1). In this context we developed a new tool.

| Method | Important advantages | Important limitations |
|---|---|---|
| Paper-and-pencil | • Basic methodology is relatively easy to learn<br>• Relevant variables can be easily included (e.g., certain indicators for behavior)<br>• Flexible method, adaptable to different research foci<br>• No costly equipment required | • Trained researchers are needed, especially if many variables will be collected at the same time (interrater reliability)<br>• The presence of the observer might be noticed by the visitors<br>• Costly one-by-one tracking (many research hours for large data sets)<br>• Data transfer from observation sheets into analysis software is needed |
| Handheld PCs | • Same as paper-and-pencil method except for the last bullet<br>• Offered category lists make it easier to record several variables at the same time<br>• Easy data transfer into digital analysis software | • Same as paper-and-pencil method except for the last bullet<br>• Initial asset costs<br>• Initial training for handling the devices and the software |
| Videotaping | • Possibility to re-watch visitor movement and behavior<br>• No observer needs to follow the visitors | • Costly one-by-one tracking (many research hours for large data sets)<br>• Mostly limited in the observed area (range of the camera)<br>• Initial asset costs and training |
| Automated systems | • Automatic collection of spatial and temporal information can ensure standardized data collection<br>• No observer needs to follow the visitors<br>• Large data sets can be recorded in shorter times (several visitors can be tracked at the same time)<br>• Easy data transfer into digital analysis software | • Initial asset costs<br>• Initial training for set-up of the system and for handling the devices and the software<br>• In general no additional variables, such as indicators for behavior, can be recorded – little flexibility |

*Table 1: Summary of the advantages and limitations of different timing and tracking methods (Schautz et al., 2016)*

*Table 1: Summary of the advantages and limitations of different timing and tracking methods (Schautz et al., 2016)*

## Introducing a new visitor observation tool

Having conducted quite a few visitor studies over the last 20 years we were always confronted with the fact, that no exhibition would be further evaluated after we had finished our task. Maybe during another exhibition project, when the funding organisation (foundation or public body) would ask for “some sort of” evaluation.

As outlined above there are already instruments for effectively and efficiently gathering data from visitors via online surveys and/or through digital media tools. What we developed over the last 10yrs. is an online program, which allows

- to upload the floor-plan of a given exhibit,
- quickly define those spots, objects, etc. that are supposed to be evaluated and
- add site-specific demographic data entries.

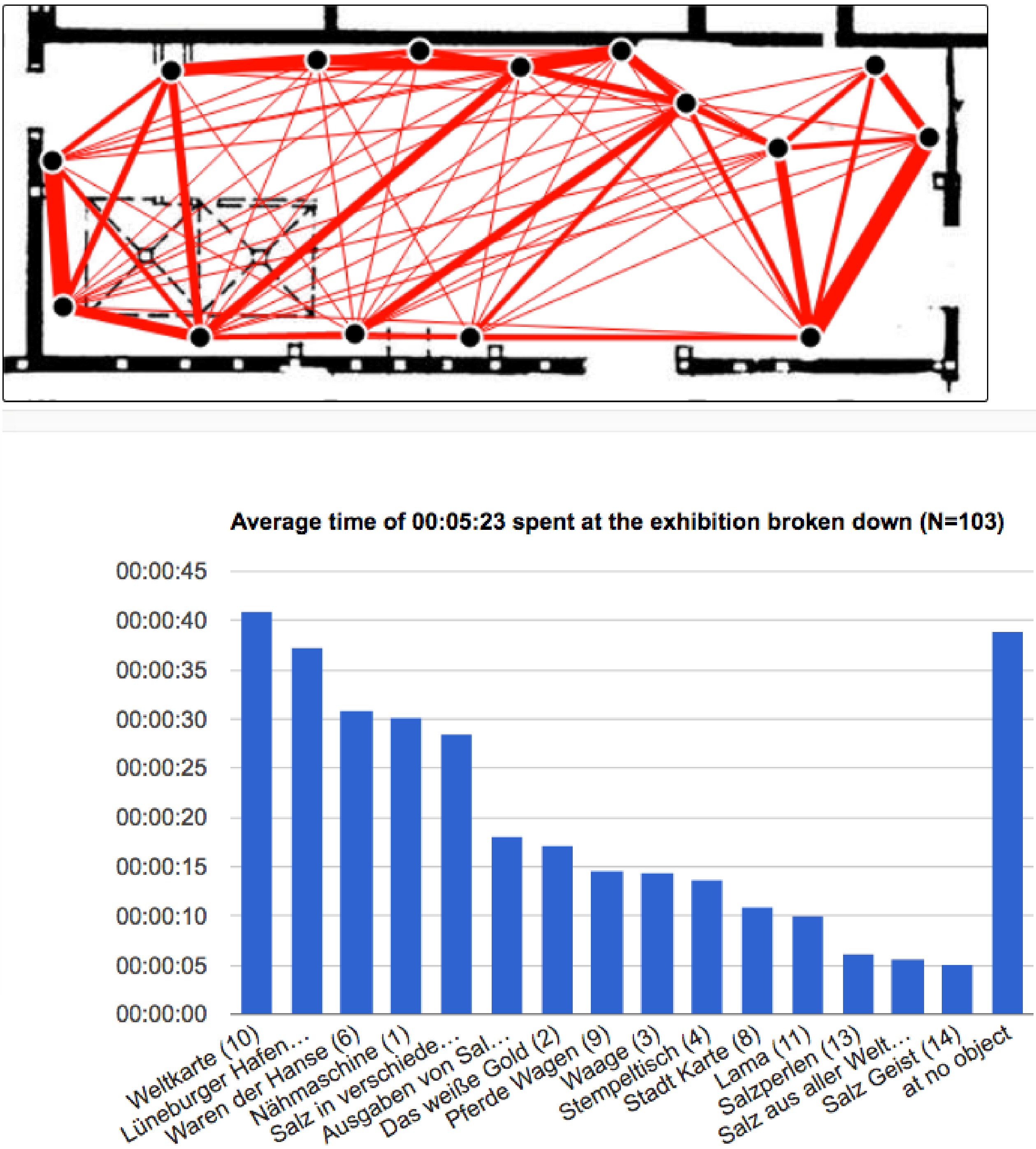


*Fig. 3. Examples of automatically generated results from the new observation tool*

Visitors are followed around and by simply clicking on the objects in question tracking and timing data are gathered and automatically processed for the exhibition (for some exemplary results see Fig. 3). Additionally, data about specified behavioural patterns can be collected and qualitative comments entered. Evaluating real behaviour is crucial when it comes to thoroughly assessing a particular exhibition. It has been proven that *fully*-automated data-collection, e.g. via RFID or beacon cannot provide a site with the data necessary for assessing it as needed (Schautz et al., 2016).

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# Round Table:
# FAIR ARCHAEOLOGY: Introducing ARIADNEplus and SEADDA

Edeltraud ASPÖCK | Guntram GESER | Gerald HIEBEL | Julian RICHARDS | Martina TROGNITZ

# FAIR ARCHAEOLOGY: Introducing ARIADNEplus and SEADDA

Chairs:
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***Keywords:*** *FAIR principles—data management—data preservation—data integration—e-infrastructures*

In this round table we presented two European archaeological projects that began this year: ARIADNEplus and SEADDA. Both are concerned with the implementation of the FAIR principles in Archaeology, so that data should be Findable, Accessible, Interoperable and Reusable.

ARIADNEplus (Advanced Research Infrastructure for Archaeological Data Networking in Europe) builds on the results of the ARIADNE project, which successfully integrated European archaeological repositories and created a searchable catalogue of datasets. ARIADNEplus will update existing data and will extend the ARIADNE dataset geographically, temporally and thematically by incorporating additional information from scientific analyses. It will develop a Linked Data approach to data discovery, providing innovative services, such as visualization, annotation, text mining and geo-temporal data management. Innovative pilots will be developed to test and demonstrate the innovation potential of the ARIADNEplus approach.

The COST Action SEADDA (Saving European Archaeology from the Digital Dark Ages) deals with the problem that, because digital data is fragile and most archaeological research cannot be repeated, there is a danger of losing a generation of research to the Digital Dark Age. To mitigate this crisis SEADDA brings archaeologists and data management specialists together to share expertise and create resources that allow them to address problems in the most appropriate way within their own countries. It will bring together an interdisciplinary network of archaeologists and computer scientists; experts in archaeological data management and open data dissemination and re-use. It will examine the state of the art for archaeological archiving and build capacity by organising meetings and training to allow archaeologists from countries with archiving expertise to work with those with fewer options, sharing knowledge and encouraging dialogue.

The format of the round table was presentations and discussions.

# Retrieving and Integrating Archaeological Data on the Web

## The Herculaneum Case Study

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***Keywords:*** *Archaeological Data—FAIR Principles—Ontologies—CIDOC CRM—Semantic Interoperability*

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### Introduction

The first of the four FAIR principles, "Findability", essentially aims at answering one of the key problems of the digital world: the data live in isolated and fragmented ecosystems, so much so that in many cases it is very difficult to find them online. This is especially true for those produced by archaeological research. The FAIR recommendations are very useful for planning future actions, but how can we deal with the already published (and somehow already "compromised" in the FAIR perspective) legacy data? Some international initiatives, such as the ARIADNEplus project, are implementing policies to provide answers to this question, availing of the consensus and collaboration of large international institutions. However, a great deal of information on the Web nowadays remains out of the reach of any integration strategy. This paper sketches a possible solution to face this issue and proposes methods to integrate archaeological information dispersed online.

### Archaeology and digital archaeology: a fragmented world

When dealing with archaeology, the dispersion we are witnessing in the digital world today finds an exact parallel (and in many cases an origin) in the real world. For centuries, the exploitation of archaeological material for private, propagandistic or commercial purposes has plagued archaeology and caused the dispersion of objects and materials, very often have ended up thousands of miles away from their original places of discovery. In the digital world, this has resulted in the online publication of data and metadata regarding this archaeological material in a myriad of different formats, languages and structures. This poses enormous obstacles to scholars who want to use the Web for their research and inevitably complicates the study of artefacts and monuments that are stylistically similar or coming from common archaeological contexts. The case we have chosen for our paper is one of the most emblematic in this regard: the artefacts originating from the archaeological excavations of the ancient city of Herculaneum.

### Herculaneum: the dispersion of an archaeological treasure

Destroyed together with Pompeii by the eruption of Vesuvius in 79 AD, Herculaneum remained in oblivion for sixteen centuries until it was discovered by chance at the beginning of the 18th century during the excavation of a well. From that moment on, the site witnessed an uninterrupted series of excavations, during which an unimaginable amount of archaeological material came to light and its objects and monuments, either legally acquired or illegally stolen, witnessed over the centuries a great dispersion over the world. A lot of them ended up in private collections and in many of the great national museums of Europe and the United States. In the last decades, most of these institutions have published their catalogues online and created metadata for each of the objects in their possession. However, it is currently impossible to use Google or any other web tool to query this multitude of archives to retrieve, for example, all the bronze statues found during a specific excavation or all the marble artefacts manufactured in Herculaneum before its destruction. A system capable of providing adequate answers to such questions would constitute an incomparable resource for scholars.

## "Semantic Herculaneum": the reassembly of a digital treasure

One of the possible solutions to build such a system consists in finding, harvesting and aggregating dispersed archaeological information on a single platform to make them interoperable and usable in an integrated way. The use of ontologies and semantic tools is essential in this context to provide data with a high level of standardisation and to preserve the digital provenance, i.e. the connection with the information on the original websites, along the whole process. To test the feasibility of our approach, the web catalogues of the Getty Museum, the Staatliche Museen zu Berlin, the Museo Archeologico Nazionale di Napoli and the British Museum were chosen for the large number of Herculaneum artefacts they currently host. A series of special ad hoc scripts have been developed to exploit the specific query facilities of each museum's website for extracting relevant information reported within the results' web pages.

Despite the diversity of data structures and encodings, strong similarities have been identified among retrieved information, especially with regard to the way in which basic data such as dimensions, materials, shapes and provenance of objects is presented. CRMarchaeo, the extension of the CIDOC CRM devoted to the description of objects and phenomena of the archaeological world, was the ontology chosen as the common language of the integrated archive. CRMarchaeo is an event-based model capable of describing artefacts in great detail by associating them with the complex web of activities in which they have been involved in their lifetime. Metadata generated using CRMarchaeo in a formal and standard language can thus narrate the history of the artefacts from their production, use and discovery up to their acquisition, status and current location.

The information extracted from the pages of the original websites has been encoded in CRMarchaeo format through a series of mapping and conversion operations resulted in a set of RDF triples. The 3M tool developed by FORTH has been used for this operation. The data extraction, mapping and conversion platform we set up allow the entire process to be re-executed in an automated way to obtain fresh and updated data if required. This way, the metadata of about 500 Herculaneum artefacts of different epochs and nature (bronzes, mosaics, marble statues, inscriptions, papyri) have been integrated without loss of information and preserving digital provenance of data (thus fostering data “Accessibility” recommended by FAIR).

In the resulting semantic graph, managed by means of the BlazeGraph database, all data are encoded in a unifying language, coexist in a single structure and are perfectly interoperable, regardless of their digital origin (see Fig. 1). Appropriate semantic search interfaces have been implemented to query the aggregated data using ResearchSpace, a tool developed by the Mellon Foundation for the British Museum that makes the graph browsable along the axes of different properties and offers interfaces for most of the advanced semantic queries defined for CIDOC CRM information, such as those based on the Fundamental Categories and Properties theorized by Tzompanaki and Doerr (2012).

ResearchSpace also allows sophisticated data analysis on integrated information, including the ability to derive knowledge on whether and how various artefacts have interacted with each other over time, and to investigate for spatial and temporal relations between them (see Fig. 2). It also allows arranging the artefacts on timelines or maps, to obtain spatial distribution and to group them according to specific criteria, such as excavation or production events, i.e. objects present in a specific area or place (like a *villa* or a *domus*) at a given time or coming from a specific *atelier*.

RDF, the standard used to encode information, allows them to be easily integrated in other CIDOC CRM-enabled environments (such as the ARIADNEplus infrastructure or the PARTHENOS Data Cloud), exported in other formats, and published as Linked Open Data. The Interoperability and Reusability of the new archive (corresponding to the “I” and “R” of the FAIR principles) are thus guaranteed.

## Conclusions

This experiment produced extremely encouraging results and has shown that the retrieval and aggregation of information published on the web can be a viable way to establish interoperability, even over non- or dis-integrated and hardly accessible data. The CRMarchaeo model has shown its full potential in providing a comprehensive language for dealing with the multiple facets of the various encodings and data formats; the tools used to manage and query the integrated semantic information avail advanced queries and in-depth analysis of the integrated data. In conclusion this activity has shown in practice how FAIR principles can be propagated even to un-FAIR data present online through the use of ontologies and standard tools.

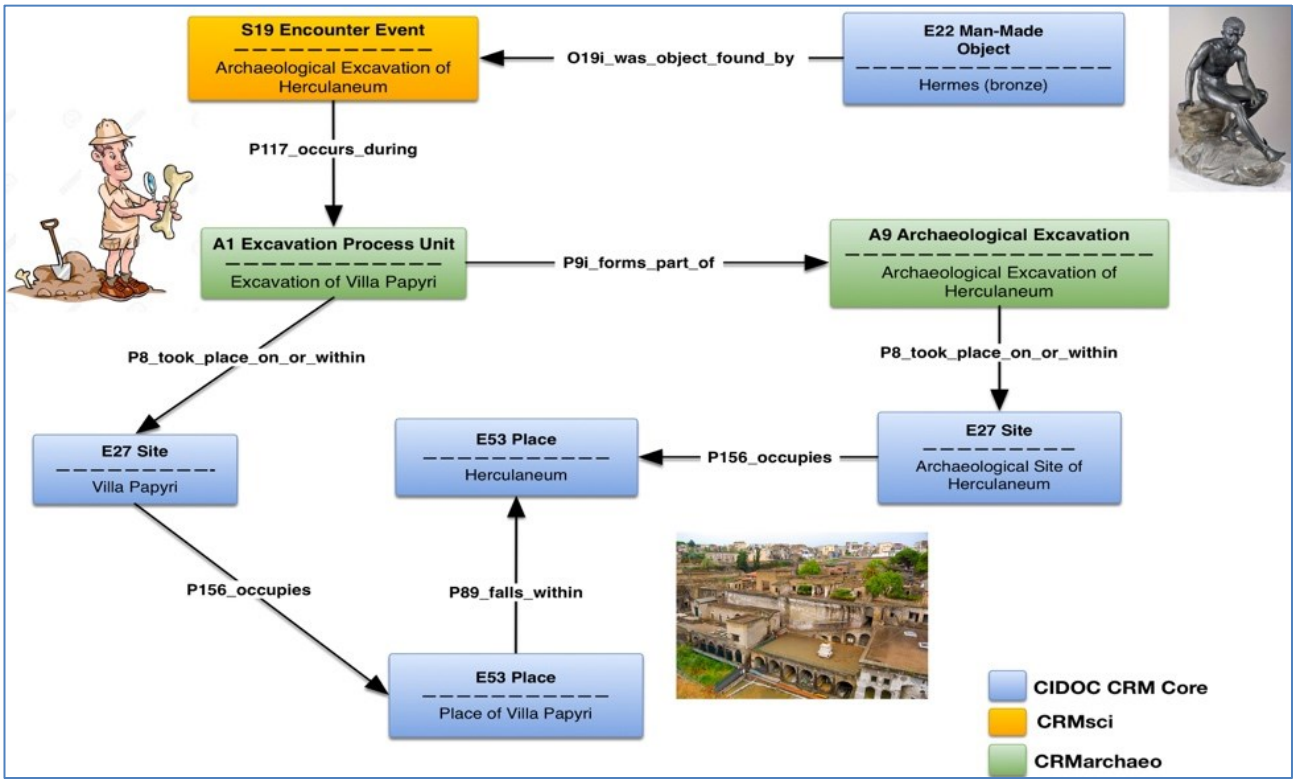


*Fig. 1. CIDOC CRM encoding of information concerning a bronze artefact coming from the Herculaneum site (© authors).*

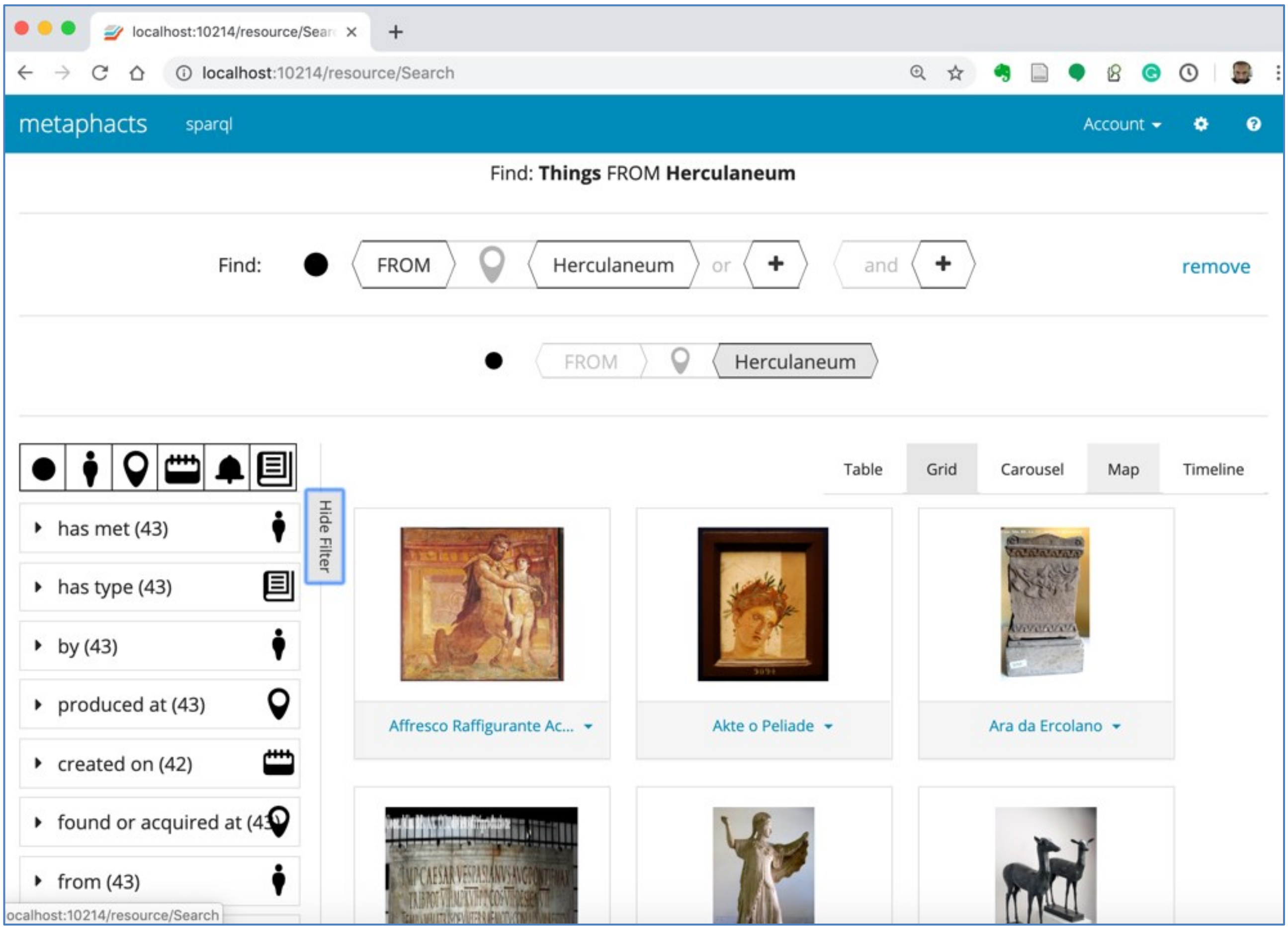


*Fig. 2. The semantic interface configured for the Herculaneum data showing various ResearchSpace query features.*

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# ARIADNEplus and community data repositories[1]

## Innovative solutions for sharing open archaeological data

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***Keywords:*** *Research Infrastructure—Repositories—Open Data*

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doi: 10.11588/propylaeum.747.

## Issues and context

Archaeology should be a field leading in data preservation, sharing and integration. Most archaeological fieldwork cannot be repeated and the digital record of excavations and other investigations is fragile but needed as evidence and basis for further research, comparative analysis and broad synthesis. However, many archaeologists in European and other countries do not have available yet a state-of-the-art digital repository for archiving and sharing their data. Digital infrastructure for finding and accessing data of repositories in different countries has only recently been established by ARIADNE, the Advanced Research Infrastructure for Archaeological Data Networking in Europe. The issue of a lack of appropriate data repositories is being addressed by the COST Action SEADDA, the Saving European Archaeology from the Digital Dark Ages network. SEADDA and ARIADNEplus share the goal of making archaeological data FAIR (Findable, Accessible, Interoperable and Reusable), especially by supporting knowledge exchange and collaboration on data repositories and infrastructure. ARIADNEplus will update existing and incorporate additional datasets in the ARIADNE catalogue, also including data from scientific analyses, and provide new data services and tools. Expansion of the pool of datasets in the years to come will depend on accessible repositories across Europe (and beyond) richly filled by the research communities.

## National-level data repositories as the most effective approach

Many European countries lack a state-of-the-art digital repository where archaeologists can deposit their data for long-term preservation and make it available to the research community. The optimal solution is building and mandating deposition of the data in a national-level repository. It is the most effective approach in several respects, including clear orientation of all stakeholders, formation of a trusted centre of expertise, guidance and support, cost-effectiveness of data curation and access (e.g. economies of scale). The alternative, particularly in large countries, is a scenario in which many

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institutions aim to build their own data repositories, with a lot of duplication of effort, implementation of different standards, and competition for scarce funding. Moreover, repositories dedicated to one institution usually accept data only from affiliated researchers.

References for national-level archaeological data repositories exist, for example the ARIADNEplus partners Archaeology Data Service (UK) and the E-Depot for Dutch Archaeology of Data Archiving and Networked Services – DANS (Netherlands). In Germany, unfortunately the development of the IANUS Research Data Centre for Archaeology and Classical Studies, funded 2011–2017 by the German Research Foundation, has been discontinued. In the United States, Digital Antiquity at the Arizona State University (also a partner in ARIADNEplus) aspires to provide a national-level repository with tDAR, The Digital Archaeological Record (McManamon et al., 2017).

The benefits of such repositories stem from their role as reliable central hubs for information and data resources which make research easier, faster and cheaper. In the case of the Archaeology Data Service (ADS) the increase in research efficiency of the users has been calculated to be worth at least 5 times the costs of operation; including other benefits £ 1 invested in ADS yields up to £ 8.30 return of investment (Beagrie and Houghton, 2013; on the development of the ADS see Richards 2017).

There are many advantages of preserved data that can be found and accessed easily in one place. For example, it can prevent unnecessary replication of work, allow verification of research integrity, promote collaboration, and combination and analysis of data to address new research questions. The Keeping Research Data Safe (KRDS) Benefits Analysis Toolkit considers over 30 benefits for researchers, institutions and society (Charles Beagrie Ltd., 2011).

Regarding business models for sustainable data repositories for archaeology the largest part of the costs will typically be covered directly or indirectly from public funds, but income from deposit charges of archives of developer-led projects and other sources (e.g. grants of private foundations) could be a significant part of a mixed model (OECD 2017). Looked at from the perspective of individual research projects the cost of data preservation for long-term access is only a fraction of the total project costs, 1–3 % depending on the type of investigation and data generated. These percentages are for project archives that require much curatorial support; “self-service” deposit of some files costs much less, e.g. tDAR charges $10 per individual file (up to 10 MB), discounted to $5 per file for purchase of 100 or more deposits (McManamon et al., 2017).

## The scenario from the perspective of ARIADNEplus

The objective of the ARIADNEplus data infrastructure is to allow researchers and other users discover and access data held and shared by repositories across Europe (and beyond). From this perspective ideally one or only few repositories per country from which data records can be aggregated is of course the preferred scenario. A proliferation of repository building projects and dispersion of archaeological data resources would make the tasks required to integrate such resources much more difficult. The tasks include a significant amount of effort for support in the preparation of data records so that advanced data search and access methods (e.g. based on Linked Data) can be applied on the aggregated pool of metadata.

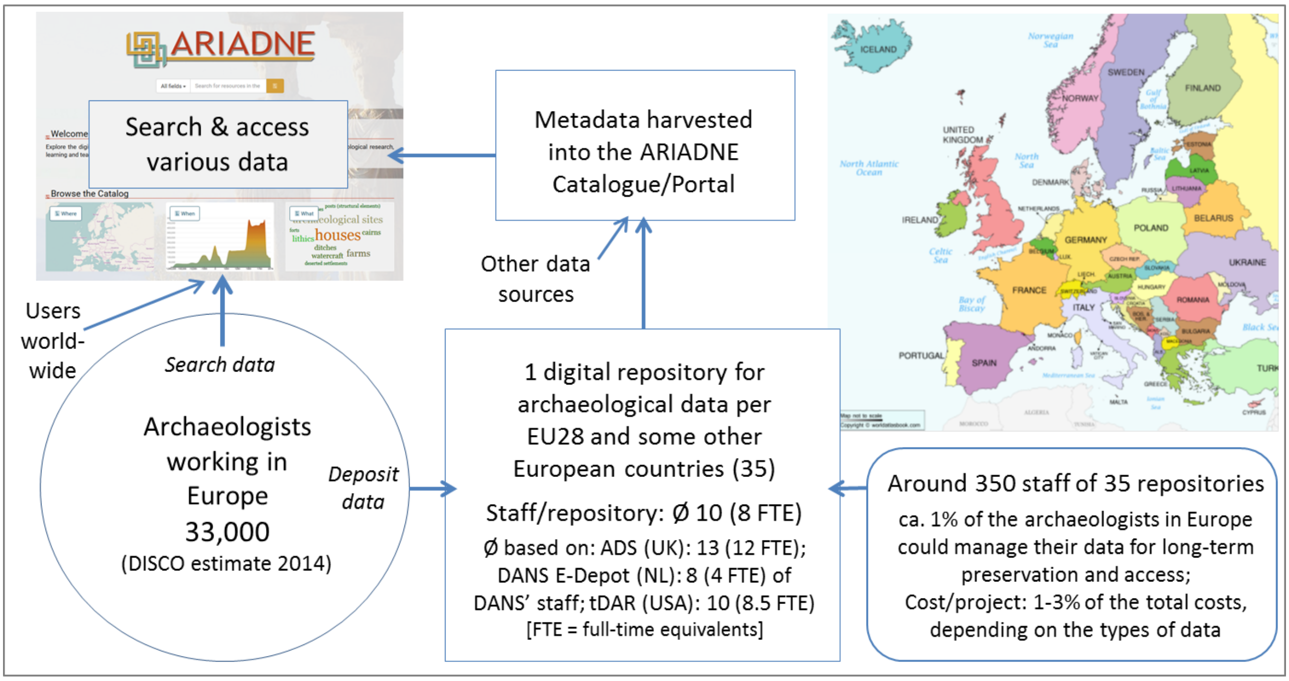


*Fig. 1. Scenario of data preservation and access in Europe based on national-level repositories (© Salzburg Research).*

Fig. 1 illustrates a scenario in which each European country (the EU28 and others) would have but one mandated national-level archaeological data repository from which ARIADNEplus harvests the metadata of datasets to feed the data search portal. The scenario shows that a small number of repository staff could acquire, preserve and provide access to valuable data from the work of the archaeologists in Europe. 35 repositories would require in total only about 300 staff, which is around 1 % of the estimated 33,000 archaeologists working in Europe (DISCO, 2014). The scenario of course does not exclude some division of work between repositories, for example, between repositories for long-term preservation and access (the focus of this paper) and repositories dedicated to particular research fields or themes in which the research community regularly updates existing and adds new datasets, research reports, etc. Such dedicated repositories may have an international scope and be maintained by institutes leading in the respective research field or theme.

## Open research data require mandates and support by research funders

Researchers often share data, but mainly with project collaborators and other trusted colleagues. Therefore, a lot of valuable data, although funded publicly, is not available to the research community and other potential users. In a survey of 1560 academic researchers of different disciplines 58 % said that they shared data with researchers they know personally while only 13 % made data publicly available (Fecher et al., 2015). A lack of academic recognition and reward, fear that data might be misinterpreted or misused, and the additional work required to prepare data for use by others (e.g. data description) are strong barriers to sharing data through an accessible repository. Therefore the core requirement for moving research data into accessible repositories is decisive open data mandates by research funders, coupled with funding of the basic costs of domain repositories and the researchers' data deposition costs (e.g. as part of research grants). Thereby, instead of being inaccessible and eventually lost, valuable research data can be preserved and become available for further research, education and other uses.

## Growing an open data culture in archaeology

Archaeological data repositories and the ARIADNEplus data infrastructure will flourish only within a research culture that values preservation, sharing and reuse of data. Archaeology should be a field leading in open (or FAIR) data because academic as well as preventive archaeology are conducted in the public interest in archaeological heritage and knowledge. The fact that much of the creation of its data results from the destruction of primary evidence makes preserving and open sharing of the digital record even more critical. However, many archaeologists around Europe are not yet well equipped and supported for archiving and sharing open data. As the matter is complex, strong leadership regarding data policies (mandates, funding), state-of-the-art repositories, training and support is necessary.

## Acknowledgement

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# FAIR Prehistoric Mining Archaeology Data in the Light of ARIADNE and SEADDA

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## Introduction

For the round table, a use case will be presented related to prehistoric mining. Data from various research projects are made available applying the FAIR data principles, which state that data should be (F)indable, (A)ccessible, (I)nteroperable and (R)e-useable (Force 11, 2019). As it is an archaeological project with archaeological resources the aim is to apply the methodologies, guidelines and infrastructures created within ARIADNE, the Advanced Research Infrastructure for Archaeological Data Networking in Europe, an European Union Infrastructure for archaeological resources (Niccolucci and Richards, 2013). In particular CIDOC CRM and CRMextensions will be used as conceptual models (CIDOC CRM, 2019). The research is integrated into the COST Action SEADDA (Saving European Archaeology from the Digital Dark Age, https://www.seadda.eu/) and benefits from the international exchange on the topic of archaeological archiving.

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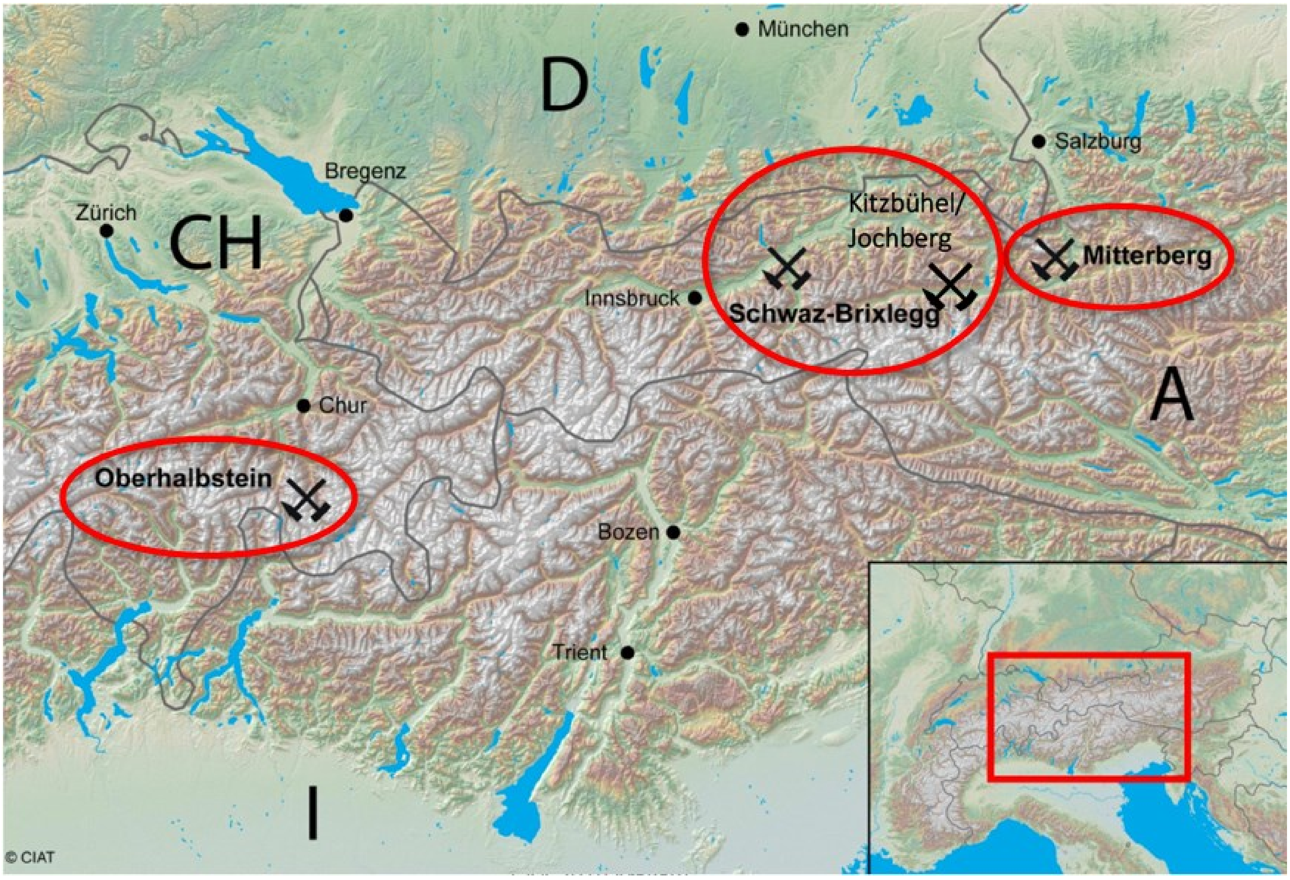


*Fig. 1. Investigation areas of the DACH Project*

## Research Data

From 2015 to 2018 four institutions from Germany (D), Austria (A), and Switzerland (CH) investigated mining, technology transfer and trade connections during the Bronze Age and Early Iron Age within the multinational DACH project “Prehistoric copper production in the eastern and central Alps—technical, social and economic dynamics in space and time”. The project had the goal to reconstruct the development and influence of three mining districts of supra regional significance—Mitterberg, Schwaz-Brixlegg and Oberhalbstein—,their economic dynamics and the manifold interrelations within the network of alpine metal producers. The Austrian part of the project investigated the mining area of Schwaz-Brixlegg and is extended with a separate Open Research Data Pilot project of the Austrian Science fund. For all these sites data was created based on archaeological field survey and excavations as well as archaeometric analysis on physical remains and relevant materials and structures of prehistoric mining and metallurgical activities. Excavations and field surveys were documented according to the guidelines for archaeological investigations of the Federal Monuments Office (Bundesdenkmalamt), which define in detail which reports, lists, photos and plans have to be created for prospections, excavations, stratigraphic units, finds, archaeological objects and groups (Bundesdenkmalamt, 2018).

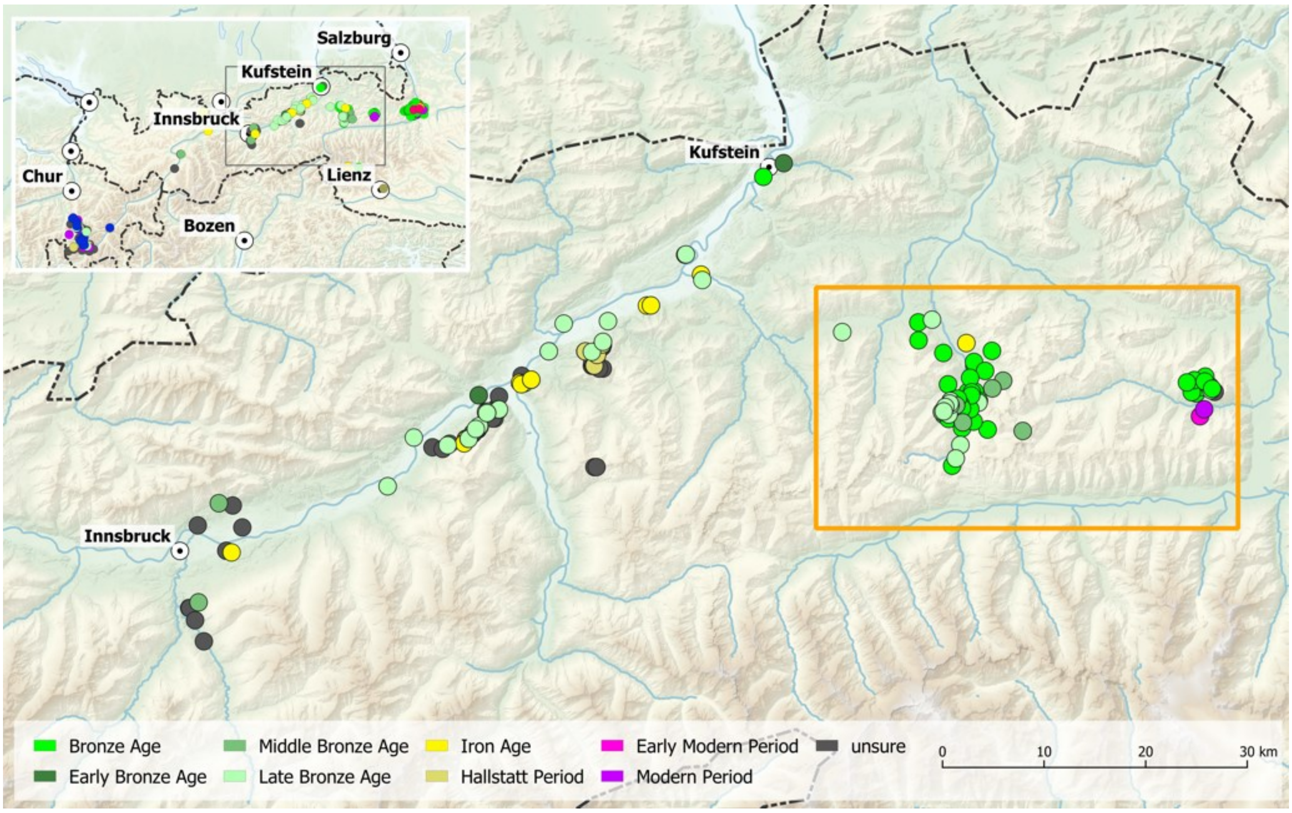


*Fig. 2. Excavation and field survey data for which FAIR data are created*

Archaeometric analysis was made on 175 axes from Western and Central Austria. The goal was to increase knowledge about the type of copper that was used and the chronological development of the use of these copper types and alloying techniques from the Early Bronze Age to the Early Iron Age in mainly Western Austria by combining archaeological with geochemical data. These analysis as well as dendrochronological and $^{14}C$ analysis are documented in different reports and statistics.

## Methodology to create FAIR data

All research data were first revisited and converted, if necessary, in the respective standard formats. These digital resources are then deposited in the Zenodo repository (https://zenodo.org/) located at the CERN Data Center which has experience in long-term archiving. Zenodo assigns Digital Object Identifiers (DOIs) which are globally unique and persistent identifier according to the (F)indable data principle and makes the resources accessible and citeable according to the (A)ccessible data principle.

In order to fulfil the FAIR principles (I)nteroperable and (R)e-usable, metadata is encoded with the CIDOC CRM ontology to satisfy the FAIR guiding principles to use shared vocabularies and/or ontologies and describe data with rich metadata. CIDOC CRM can model the semantics of the relations between research objects, the activities and actors investigating them and the data that document the results of the investigations. Explicitly stating the research activities with their methodologies and linking them with the investigating persons and institutions will create data which is associated with detailed provenance.

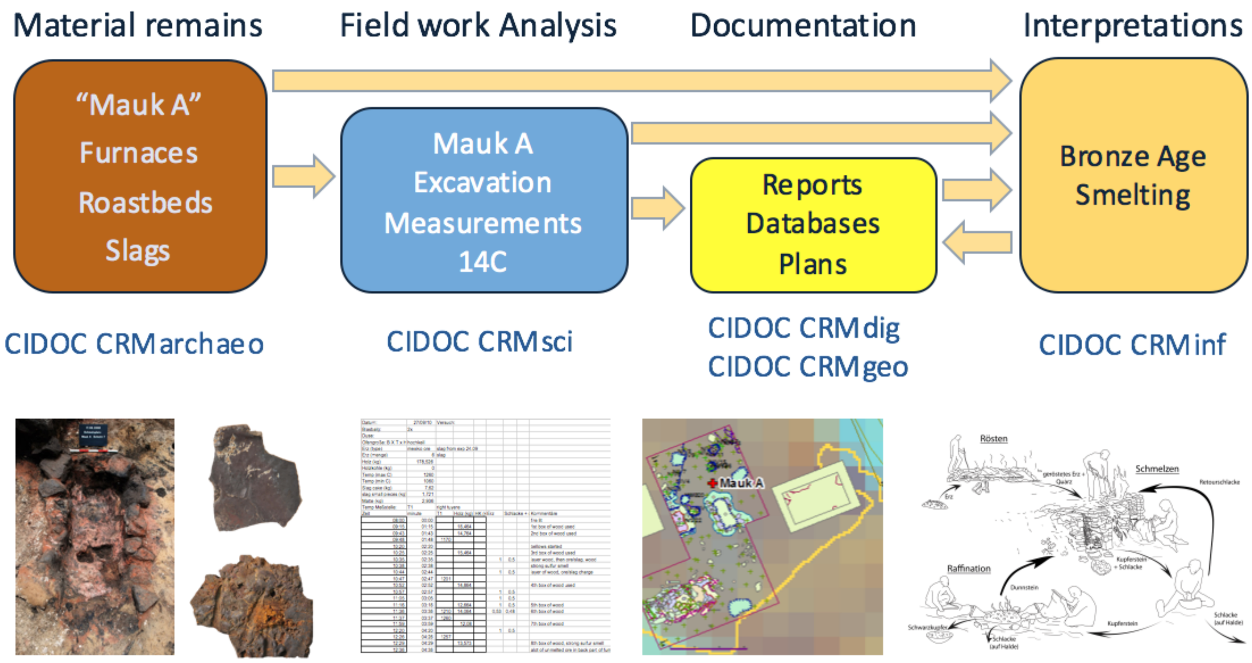


*Fig. 3. Using CIDOC CRM extensions for material remains, field work&analysis, documentation and interpretations*

## Importance of the Research

The aim was to develop an approach how to create FAIR data for prehistoric mining archaeology derived from the Federal Monuments Office documentation which is obligatory in Austria. This means that most parts of this approach is generic and can be applied for any archaeological investigation conducted in Austria as they have to produce documentation in the same way. The methodology is based on semantic web standards to guarantee (F)indability and (A)ccessibility. To make data (I)nteroperable und (R)e-useable, data is mapped to the CIDOC CRM ontology which has been adopted by the ARIADNE EU-Infrastructure for Archaeological Resources as preferred metadata schema for Archaeology. One of the CIDOC CRM extensions used in this context is CRMarchaeo which was build based on the official documentation requirements of different countries including the Austrian Federal Monuments Office. Therefore, the metadata standard employed here is adequate for the documentation at hand and in addition a consensus on a European level. The creation of the metadata and the deposition of the data at Zenodo is in progress and for the CHNT we will provide a DOI to access the data. The methodology was applied to specific data of the German and Swiss project partners as well to create an integrated data set based on CIDOC CRM and encoded in RDF. It depends on them which of the data they want to provide as FAIR data. Once the metadata for the Austrian part is completely created it will be transformed and integrated in the ARIADNE portal. In addition, the RDF data will be available through a SPARQL Endpoint, but this first has to be organized with the IT services of the University of Innsbruck, in order to provide a service that will be accessible even after the project is finished.

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# Introducing SEADDA

## Saving European Archaeology from a Digital Dark Age

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***Keywords:*** *FAIR principles—Digital Preservation—Data Management—COST Actions*

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### Introduction

Making archaeological data open and freely accessible must be a priority across Europe, but this cannot be achieved unless that data can be archived, migrated and disseminated within a persistent repository, in accordance with the FAIR (Findable, Accessible, Interoperable, Reusable) principles. The depth of the problem for archaeology has become starkly apparent through the work of EU projects such as ARIADNE[2] (Advanced Research Infrastructure for Archaeological Dataset Networking in Europe) (Aloia et al., 2017). Data often languishes in unreadable formats with inadequate metadata, and it is no exaggeration that Archaeology is facing a Digital Dark Age unless urgent action is taken. However, projects such as ARIADNE have also revealed the key to mitigating the crisis is to bring archaeologists together to share expertise and create resources that allow them to address the problem in the most appropriate way within their own countries (Wright and Richards, 2018). Important international standards exist, such as the OAIS (Open Archival Information System) standard for digital preservation, the Core Trust Seal for repository accreditation, discipline-based standards for file formats and metadata, such as those proposed in the Archaeology Data Service (ADS)/ Digital Antiquity Guides to Good Practice (Fig. 1). However, there is no single way to build a repository, although to be successful, archaeologists must be at the decision-making heart of how their data is archived, to ensure re-use is possible. It is also clear that there is an appetite for data re-use (e.g. Fig. 2) and that we can build on the experience gained by organisations such as the ADS, DANS, SNDS and the DAI (e.g. Richards et al., 2013; Richards, 2017).

This paper will introduce a new COST (European Cooperation in Science and Technology) Action: SEADDA (Saving European Archaeology from a Digital Dark Age), which started operation on 1 May 2019 and will run for four years.[3] SEADDA will play a vital role in establishing an international network of expertise in archiving and disseminating archaeological data. It includes archaeologists from

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[2] http://ariadne-infrastructure.eu/

[3] https://www.seadda.eu

nearly every European country, as well as four international partners (Argentina, Canada, Japan, and the United States). It brings together archaeologists, experts in archaeological data management, and experts in open data dissemination and re-use. SEADDA will create publications and materials that will set out the state of the art for archaeological archiving across Europe, and recommendations to mitigate the crisis. It will organize meetings and training that will allow archaeologists from countries with archiving expertise to work with archaeologists with no available archiving options, so they may share knowledge and create dialogue within their countries to move forward. It will allow countries to see where gaps exist and how they might collaborate to address issues together. Participants in this CHNT Round Table session will also be invited to contribute their own experiences to the discussion.

SEADDA comprises four working groups, reflecting different levels of experience of the partners, and their specific interests:

### Stewardship of archaeological data

WG1 brings together those with varying levels of experience to share their successes and challenges in this area, not only for knowledge transfer, but to understand where opportunities may lie for members to support each other in their efforts to move forward. It aims to explore ethical considerations regarding the extension of stewardship of the archaeological record to include preserving digital data, and whether professional guidance exists on a regional or national level. It also considers issues of responsibility as to where and how data should be preserved, and who is legally required to fund the short and long-term costs of preservation.

### Planning for archiving

WG2 explores the practical issues surrounding the creation of an appropriate repository for archaeological data. This will range from understanding hardware and software options for those needing to set up an archive in their country, management structures, and the training of archivists. It considers existing best practice, changing future needs, and pragmatic technical and structural solutions.

### Preservation and Dissemination Best Practice

WG3 seeks to understand international best practice regarding archiving and preservation. It is exploring current practice in digital archiving and preservation generally, including repository accreditation, and the implications surrounding working with the myriad forms of archaeological data. It is also surveying future trends to understand the changing digital landscape and how digital archaeological practice may change.

### Use and Re-Use

WG4 is seeking to understand how to optimise archives and interfaces to maximise the use and re-use of archaeological data. It will explore how archaeological archives can better respond to user needs, and ways to document and understand both quantitative and qualitative re-use. This will include understanding barriers to re-use, such as IPR and licensing, but also issues around the design of underlying data structures and their interfaces.

Together, our Working Groups aim to address each of the FAIR principles from an archaeological perspective.

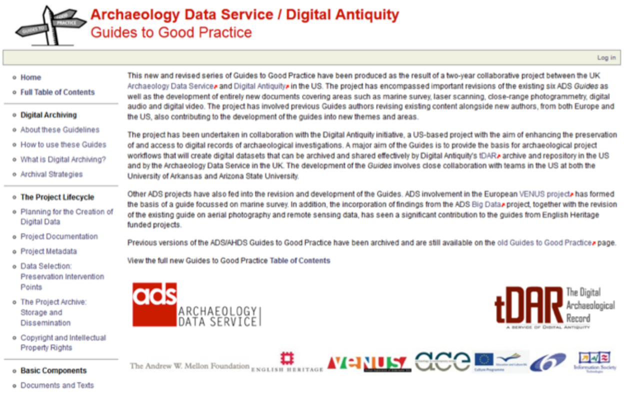


*Fig. 1. Archaeology Data Service / Digital Antiquity Guides to Good Practice*

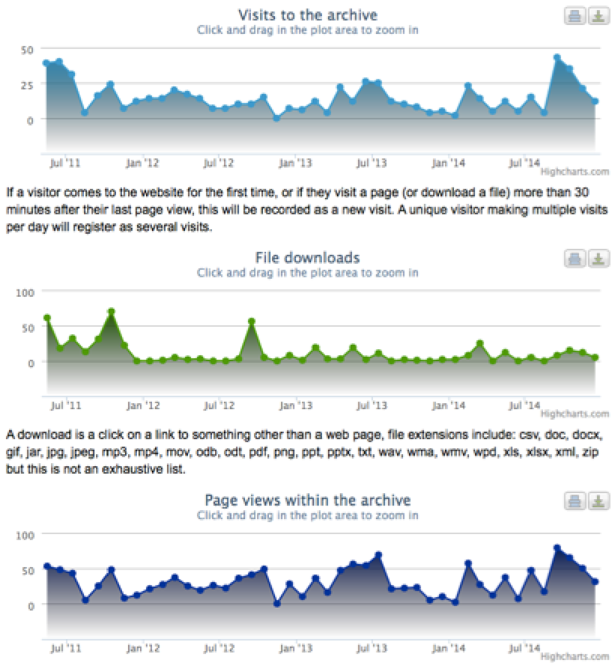


*Fig. 2. Re-use figures for an example digital archive*

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# Round Table:
# Visualizing Hypotheses: Practical Handling of Uncertainty in Digital 3D Models

Christiane CLADOS | Heike MESSEMER

# Visualizing Hypotheses: Practical Handling of Uncertainty in Digital 3D Models

Chairs:
Christiane CLADOS, Philipps-Universität Marburg, Germany
Heike MESSEMER, Julius-Maximilians-Universität Würzburg, Germany

**CHNT Reference:** Clados, Cristiane and Messemer, Heike. 2021. Roundtable: “Visualizing Hypotheses: Practical Handling of Uncertainty in Digital 3D Models”. Börner, Wolfgang; Kral-Börner, Christina, and Rohland, Hendrik (eds.), Monumental Computations: Digital Archaeology of Large Urban and Underground Infrastructures. Proceedings of the 24th International Conference on Cultural Heritage and New Technologies, held in Vienna, Austria, November 2019. Heidelberg: Propylaeum.
doi: 10.11588/propylaeum.747.

## Discussion and Future Work

Digital 3D reconstructions of cultural artefacts, historical characters and architecture contribute to a better understanding of cultural heritage. In the broad user community, experts from various fields such as architecture, archaeology, art history, paleontology, forensic anthropology, and museology generate 3D reconstructions in order to gain insight into no longer existing evidence. Therefore, such reconstructions are a critical tool for the “translation” of scientific data into visualizations, which make these accessible to the expert community and the general public. It is important to keep in mind that uncertainties are part of nearly all digital 3D models of historical objects due to a lack of sources, ambiguities, interpretation of sources etc. Therefore, strategies have to be found to cope with uncertainties, to visualize them and to communicate them to the audience.

This topic is relevant for many disciplines and seemed particularly appropriate for a multidisciplinary conference like CHNT 24, which took place from 3rd to 6th November 2019 in the Vienna City Hall. To open this topic for discussion in the scientific community the roundtable *Visualizing Hypotheses: Practical Handling of Uncertainty in Digital 3D Models* was conceptualized, which took place on November 4th. Central to the subject of the roundtable were questions like: How to deal with uncertainties in architecture, objects, historic individuals, and fossils? How can hypotheses be visualized in presentations for experts and the general public? Furthermore, the state of the art, and determining factors of a hypothetical visualization were part of the discussion in the roundtable. Four speakers with different scientific backgrounds and from different disciplines—Katharina Ute Mann, Dominik Lengyel, Marcin Szyma, and Oliver Bruderer—were invited to present innovative theories and methods. The present paper serves to reflect on the lectures and in particular on the subsequent discussion.

We wish to express our thanks for the interest and cooperation of the CHNT 24 staff to make this roundtable a success, particularly to Wolfgang Börner, the organizer of CHNT, and to the speakers of the roundtable.

## Short descriptions of presentations

The first presentation was given by Oliver Bruderer, who is a freelance artist and science illustrator with a great expertise in archaeological visualization.[1] Between 2012 and 2016 he was student of the Zurich's University of Applied Sciences (ZHdK) and has received a Bachelor of Arts in Design and Scientific Visualization. He gained practical experience in several projects in Greece, Turkey and Egypt and created numerous archaeological visualizations as part of excavations of the German Archaeological Institute.

In his talk "From the fragment to the big picture. Virtual reconstruction of a fragmented terracotta sculpture" he presented a project led by the German Archaeological Institute's Athens Department in the village Kalapodi in the South Eastern part of Greece. In the focus of the talk was the 3D reconstruction of a large terracotta horse acroterion from the archaic period. The fragments were digitalized using "Structure from Motion" (SfM), generating a 3D model based on multiple photographs. In Cinema 4D Studio (Maxon) the fragments were aligned virtually and missing parts were 3D modelled manually. The aim was to explain visually how the remaining parts form the historic object in conjunction with the reconstructed parts. This was possible in a series of visualizations and especially due to color codes of the different parts.

The second talk presenting a completely different method was given by architect Dominik Lengyel.[2] Since 2006 he is professor of Architecture and Visualization at the Brandenburg Technical University Cottbus-Senftenberg. He conducted numerous 3D projects focusing on the visualization of past architecture, for example TOPOI "The Formation and Transformation of Space and Knowledge in Ancient Civilizations" (2007–2019). In December 2019 his new project titled "Architecture Transformed—Architectural Processes in the Digital Space" started, in cooperation with the Institute of Art History at University Marburg and funded by the German Research Foundation (DFG).

Dominik Lengyel focused on the design of abstraction in his talk "Architectonic design as method of visualizing hypotheses. A direct translation from verbal into visual architecture". He argues that a reconstruction of lost architecture is not possible, as that would mean to construct the building for a second time. Instead, he aims at visualizing lost architecture by including its "architectonic planning and thinking"[3] and he explains that "the design of abstraction is our way of including the visualization of hypotheses and the visualization of the architectural design, that is its original idea."[4] For the visual appearance this means that the architecture is being visualized in grayscales partly as abstract, schematic three dimensional objects and partly rich in architectonic details, depending on the level of uncertainty.

The following talk was held by art historian Marcin Szyma on "A digital reconstruction of a lost work of micro-architecture. Example of the alabaster tomb of St Hyacinth in the Dominican church in Cracow".[5] In his dissertation Marcin Szyma focused on Dominican church and monastery in Kraków in

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[1] For more information see Oliver Bruderer's website: http://oliverbruderer.ch/ (Accessed: 31 March 2020).

[2] For more information see website of the architect's studio: https://www.lengyeltoulouse.com/ (Accessed: 31 March 2020).

[3] Lengyel, Dominik: Architectonic design as method of visualizing hypotheses. A direct translation from verbal into visual architecture, long abstract for CHNT 2019, pp. 1–3, here: p. 3 (unpublished).

[4] Ibid.

[5] For more information see website of the Jagiellonian University: https://ihs.uj.edu.pl/instytut/wykladowcy/szyma (Accessed: 31 March 2020).

the 13th century. He is working at the Institute of Art History at the Jagiellonian University in Kraków. His latest research project “The Architecture and Furnishing of the Dominican Church and Friary Complex in Cracow, from the first half of the 13th c. to the present” is a cooperation with his colleagues and co-authors Jacek Czechowicz (Institute of History of Architecture and Monument Preservation, Faculty of Architecture, Cracow University of Technology), Krzysztof Czyżewski (Wawel Royal Castle, State Art Collection), and professor Marek Walczak (Jagiellonian University in Kraków) and is financed by the Polish National Science Centre.

In his talk Marcin Szyma introduced this joint research project dealing with the digital reconstruction of the tomb of the Dominican St Hyacinth. During the centuries the knowledge about the exact location of the tomb was lost. The project focuses on the evaluation of the past research on the tomb and the testing of hypotheses of its location using digital technologies. A laser scan of the church serves as the basis to identify fragments of the original tomb and to identify possible locations of the tomb. The researchers use colors to differentiate between still existing parts and reconstructed parts to visualize hypotheses.

The last talk was presented by art historian and editor Katharina Ute Mann.[6] She received her binational doctorate with focus on “Polonia – a national allegory as a place of memory in Polish painting of the 19th century” in 2013 at the University of Cologne and the Akademia Ignatianum at Crakow. Currently she is working on her postdoc project “Reenactment of antiquity in form and color by J. J. Winckelmann until today”. Her main interests are the reception of antiques, antique painting, and color reconstructions of antique sculptures. Further interests concern art historical places of memory, paintings in Poland, freemasonry, and Palladianism of the 19th century.

In her presentation “Hypothetical reconstruction of antique sculptures in colour” Katharina Ute Mann explained how hypothetic reconstructions of colored antique sculptures are an added value for research. As this group of historic objects is mainly preserved with a white surface and a lack of the original coloring, it is important to indicate the initial appearance of the sculptures and herewith offering insight in the idea of an ancient Zeitgeist. She uses digital technologies to test easily different variants of hypotheses of color schemes. Furthermore, she examines the aesthetic effect and possible functions of the sculptures.

## Discussion after the presentations

In the subsequent discussion, which was open to the audience, special aspects and questions that arose from the presentations were reflected. Since the topic of the round table focused on visualization of uncertainties, the aspect of accuracy was a major concern. Oliver Bruderer, for example, made the statement that accuracy is given when hypothetical elements of the reconstruction are indicated. This represents a new perspective on the creation of hypothetical reconstructions in which the concept of accuracy has so far been associated with the selection of a certain type of evidence. The type of evidence, as known so far, will dictate the level of accuracy, as does the availability and quantity of evidence. In this respect, the conclusion that the reconstruction is already accurate due to the marked hypothetical parts represents a new state of knowledge.

[6] For more information see Katharina Ute Mann’s website: https://katharina-ute-mann.jimdofree.com/ (Accessed: 31 March 2020).

Another important point concerned the use of colors in hypothetical reconstructions. In general, colors play an important role in the creation of digital reconstructions. They endow surfaces with properties and thus act as carriers of meaning, because they can be used to visually convey complex information about the model. Methods of representation vary from abstract-conceptual to imitating reality. Katharina Ute Mann, for example, points out the importance of reconstructing ancient sculptures in their original colors. The transience of pigments makes it almost impossible to adequately communicate the ancient idea of colored sculptures, which solidifies the perception of a monochrome-white antiquity: “Not only that the risks will highly create an untrue image of the ancient world, it provokes fundamental changes in the aesthetic perception” (Katharina Ute Mann). This approach is also supported by Franco Niccolucci (2006, p. 22) when he notes in the case of the Mayan city of Calakmul—in what is now Campeche—that the ruins overgrown with vegetation give the visitor a far less clear impression of the former appearance of the city compared to a 3D reconstruction in a realistic style. In the case of Greek sculptures, Katharina Ute Mann also points out other aspects that speak for the reconstruction of past colors. It is known from many ancient cultures that colors convey meaning. Colors therefore have enormous relevance for the interpretation of sculptures and only become “legible” through them, as Vinzenz Brinkmann (2017, p. 27) describes. Another important aspect is that the reconstruction of the former color of the sculptures generates the idea of *Zeitgeist*. This is in strong contrast to the abstract-conceptual use of color, as can be seen in the presentations by Marcin Szyma and Dominik Lengyel. Conceptual surface representations show no realism in the rendering of materials, but apply abstract schemes (such as color scales, grayscale, hatching or specific properties of the reproduced object). In Marcin Szyma’s presentation, for example, color was used to mark a status: lost work of the micro architecture was shown in green, while complete sections were represented with realistic colors and textures. On the other hand, Dominik Lengyel’s reconstructions are characterized by their lack of color indicating the visualization of an architectural idea instead of real architecture.

## Final thoughts

The presentations and the discussion clearly showed the diverse field of possibilities, concepts and methods of how to indicate hypotheses. All of them have their own right to exist, there is no right or wrong, but a multitude of options. The decision of which option to use depends on several aspects like the research question, target group, mode of presentation, state of the examined object, quality and quantity of source material and much more. In special cases it is even a question of philosophy.

The most important result of the discussion was that it is essential to mark hypothetic parts of a 3D reconstruction, and to choose an appropriate stylistic device to indicate the status of uncertainty. In contrast to this an unresolved question still is whether there will be standards or general guidelines to assist research regarding how visualizations of hypotheses can be designed in the future. In order to answer this question, more individual studies are needed, from which standards can be worked out.

## Towards Standardization

Nevertheless, preliminary standards can be formulated based on the results of the discussion. These concern in particular the use of color to mark uncertainties. The presentations and subsequent discussion showed that the use of color varies depending on the visualization style. Two main styles can be identified here, Conceptual Style and Realistic Style, which represent diametrically opposed concepts. Reconstructions done in the Conceptual Style do not show any realism in coloring surfaces, but instead assign abstract meaning to them by the use of color scales or grayscale. Color scales are divided into gradations of color tones, each of which is linked to a specific meaning, for example the range between hypothesis and finding (Apollonio, 2016; Maekelberg and Boeykens, 2017; Boeykens, 2011). The viewer of the 3D reconstruction can see at a glance which parts of the objects are hypothetically supplemented in the digital model and which are based on reliable findings, as for example was demonstrated by the presentations of Oliver Bruderer. A primary step toward standardization must be to determine the relation of color and meaning. When using grayscale, for example, standardized gray tones should transport different levels of information. In the case of reconstructions done in the Realistic Style, the use of color is very different from that in the Conceptual Style. Here, colors serve to realistically imitate surface properties. It is therefore not possible to transport abstract information through color. A way to solve this problem could be the use of different levels of transparency. But in this case, too, there is a lack of well determined gradations so far.

As was shown, there are possibilities to establish two completely different styles of visualization of hypotheses in digital 3D models—Conteptual Style and Realistic Style. To fully acknowledge them as standards the community active in 3D reconstruction has to define common guidelines for color and grayscales as well as for levels of transparency. This would be a major step in further establishing 3D reconstructions as research methods and tools, and as a presentation medium in the scientific community.

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# From the fragment to the big picture

## Virtual reconstruction of a fragmented terracotta sculpture[1]

Oliver BRUDERER, scientific illustrator & MA design student, Switzerland[2]

***Keywords:*** *3D visualisation—virtual reconstruction—sculpture—visualising evidence*

**CHNT Reference:** Bruderer, Oliver. 2021. From the fragment to the big picture. Virtual reconstruction of a fragmented terracotta sculpture. Börner, Wolfgang; Kral-Börner, Christina, and Rohland, Hendrik (eds.), Monumental Computations: Digital Archaeology of Large Urban and Underground Infrastructures. Proceedings of the 24th International Conference on Cultural Heritage and New Technologies, held in Vienna, Austria, November 2019
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## The project's background

The excavations by the German Archaeological Institute's Athens Department in the Greek village Kalapodi began in 1974. Since 2014 they continue under supervision of the head of department Prof. Dr. Katja Sporn. The research focuses on a sanctuary that shows continuous use from the Mycenaean to the Roman period and is generally associated with the Apollon sanctuary of Abai. The topic of this paper is the virtual reconstruction of a large terracotta horse acroterion, which was found in the context of the southern temple dating to the archaic period. (For the find see W.-D. Niemeier, [2009, p. 108]. The terracotta acroteria and figurines are being studied by Katja Sporn. For the latest excavations in Kalapodi [see Sporn et al., 2017]).

## Digital Reconstruction

Although the various fragments were excavated already years ago, previous reconstruction attempts stayed incomplete due to large areas missing. Virtual 3D reconstruction proved to be an easy and valuable approach to fit the diverse fragments together and give a suggestion about the sculpture's original appearance. Because the reconstruction process itself was in some aspect also an evaluation of the find, it was important for the final visualisations to show not only the relation between original find and reconstruction (interpretation), but also how each single fragment matters to the complete statue.

### Digitisation of the sculpture's fragments with SfM

The starting point consisted of 18 fragments that could clearly be identified as being part of the horse acroterion and were large enough to be relevant for the reconstruction. To restore the sculpture virtually, digitising the fragments was the first step. A fast and easy method to accomplish such was

[1] I would like to especially thank Prof. Dr. K. Sporn for her support with this paper, as well as M. Sartori (Universität Basel) for valuable feedback.

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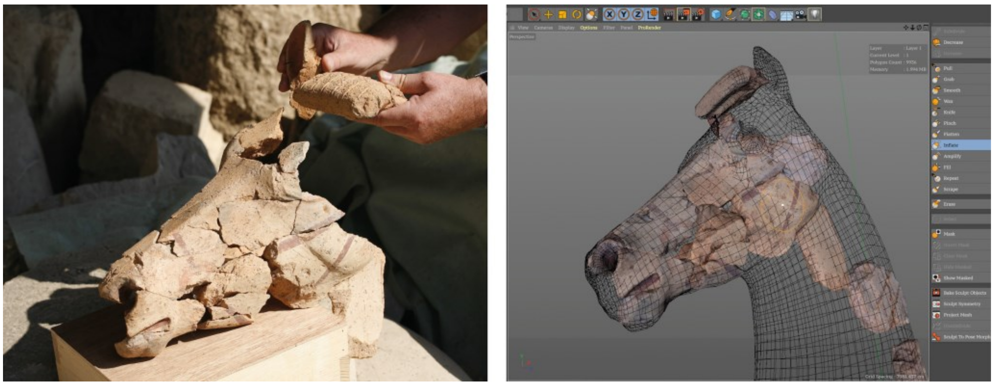
“Structure from Motion” (SfM), a method to easily generate detailed and textured 3D models to an object out of multiple photographs. The 3D models of the fragments were then directly imported to Maxon’s Cinema 4D Studio, where all the rest of the work was done.

**Assembling the fragments**

To align all fragments one to another, it made sense to start with the best preserved parts, belonging to the area of the head. The lower parts were oriented separately and eventually combined with the fragment assembly of the head. As a third step, all the fragments in between and without any direct matching were positioned as best as possible.

Although the alignment of the various fragments was performed digitally, it was crucial to have the find objects available nearby and to double check every single connection or assumption made. Through that, even tiny traces of paint could be discovered by eye that eventually played an important role to the orientation of some fragments.



*a* *b*

*Fig. 1. a) First reconstruction attempts by hand proved to be rather difficult due to large areas missing. (Photo from 2011 © Deutsches Archäologisches Institut, Abteilung Athen) b) Digital modelling directly on top of the placed SfM models. (© DAI Athen / Oliver Bruderer)*

After the alignment of the fragments, the missing parts were complemented and a 3D reconstruction was made directly on the SfM 3D models and with the help of 3D sculpting tools. At last the texture was applied and the painted areas replicated, according to the preserved traces on the fragments (see Fig. 2b).

Comparison with contemporary artistic depictions (vase paintings and sculptures) of horses helped to get an idea of possible stylistic appearance. The whole process was accompanied by the expertise of Prof. Dr. Katja Sporn and the conservator Angelos Sotiropoulos. A meticulous documentation accompanied the whole reconstruction process and makes it possible to understand the decisions made even in retrospective.

But the understanding of the process should not be limited only to text, instead it should get represented in the visualisation itself.

**The final design**

The aim of the visualisations as the end product of the whole reconstruction process was not primarily to show a restitution of the sculpture in its original state. Since the reconstruction process itself contributes to the understanding of the archaeological finds (Adkinson and Adkinson, 1989, p. 131), it was evident enough that the path from the fragments as archaeological find (Fig. 2a) to the restitution as a product of archaeological interpretation (Fig. 2b) needed to be visualised somehow. That was achieved through an easy solution by showing both the find material and the reconstruction together (Fig. 2c). This allows seeing and comparing them together, whilst they visually melt in enough to get the impression of the complete object.

a b c d

*Fig. 2. different renderings show different aspects: a) the placed SfM fragments b) the complete reconstruction of shape and surface colour c) the fragments and the reconstruction combined d) colours from red to yellow indicate the certainty for the position of each fragment (© Deutsches Archäologisches Institut, Abteilung Athen / Oliver Bruderer)*

Still, when we consider the aspect that a reconstruction is the result of logical reflection and argumentation rather than that of free artistic creation (Golvin, J.-C., 2012, p. 80), we are left with the problem that some fragments could not be aligned as certainly as others, which is not evident from simply showing find and reconstruction in comparison. To visualise the rather abstract concept of uncertainties accurately, different colours were used to show different previously defined levels of certainty as follows: Parts with direct connection to other parts were assigned a yellowish hue. Fragments that did not have a direct match but could be determined in orientation and location fairly precise through traces of colour, surface treatment or structure of the clay, received an orange colour as indication. The last category of only roughly assignable fragments was marked red. The choice of colour was mainly an artistic one, but going from colder to warmer hues to mark the more critical alignments makes sense as well.

The strategy to use colour code to show “archaeological evidence” gets already recommended in detail by other practitioners (Resco P. A. & Figueiredo C. published a concept they call “Scale depicting historical / archaeological evidence” basing on an idea of the project “Byzantium 1200”). The quoted example focuses rather on the type of source (e.g. preserved structures, pictorial depictions, written sources etc.) rather than on fragments in comparison.

## Final thoughts

This case study hopefully makes evident that a reconstruction visualisation does not necessarily end with the picture of a perfectly restored object or structure, but has also the potential to bring up visual argumentation for an archaeologists interpretation. As in the previously discussed example, that could be achieved by including the find objects directly in the reconstruction, or by colour coding important aspects. The various visualisations produced in this project were all rendered out with the same camera angle, with the idea to enable using them in an interactive environment. Switching between the different representations would allow the observer additional insights by personal comparison. This could be pushed even further to an interactive 3D environment or virtual reality.

But however far we bring this on a technical level, the additional value is given through the insights that we allow to the observer, to see not only the end product but the path of interpretation itself.

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# Architectonic design as method of visualizing hypotheses

## A direct translation from verbal into visual architecture

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***Keywords:*** *knowledge—uncertainty—design—abstraction—architecture*

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## Introduction

Visualizing hypotheses is a claim that answers the needs of the expert community—as well as the general public—for exchanging and understanding the complexity of historical research in a visual way. As manifold as the demands of either side are, as manifold are the possible—and partly well established—methods for visualizing.

Apart from traditional archaeological drawing techniques—as for example found in the volumes "Altertümer von Pergamon"–that visualize both findings and hypotheses—well distinguishable by dotted lines for example—archaeologists originally and primarily used computer aided design techniques for cataloguing both remains and hypotheses in a visually unambiguous way by using color schemes and diagrams in 2D and increasingly also in 3D. On the other hand and at the same time computer graphic designers have been proceeding in simulating architecture up to the actual state of art where a visual distinction between reality and virtuality is not possible any more.

Both computer aided approaches diverge and aim for very specific tasks, none of which is combining scientific knowledge and immersive spatial experience at the same time. The gap that our approach fills, is their combination with several targets. The first is a visual communication base for scientific exchange and mediation, the second is the valuation of architectural design, concepts and ideas as such.

## Uncertainty

A common feature though of any attempt to describe or visualize lost architecture is its inherent uncertainty in knowledge. Uncertainty in knowledge does not mean the fragility of scientific thinking as such. On the contrary, what we and our cooperating scientists of the fields archaeology and

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building archaeology have been calling uncertain knowledge is the adding up of certain knowledge e.g. of findings, obvious completions e.g. of walls upon foundations, very probable assumptions e.g. of roofs above enclosed spaced, and last but not least analogies e.g. of shapes of buildings or building parts that may be derived from other and just better preserved cases, the latter being potentially ambiguous or even contradictory depending on its respective and evenly potentially ambiguous underlying assumption, both being equally strictly scientific and well founded.

Still there are many approaches for as many demands in visualizing hypotheses. In probably most cases, the preference lies on showing the hypothetic content of buildings or building parts unambiguously, meaning that the spectator understands uncertainty immediately and without a doubt. This fulfils the general demand for unambiguity that is equivalent with a general hesitance against subtlety and complexity. As clear this approach of obvious declaration of uncertainty is, at the same time this means to exclude many other features that can be mediated by a visualized hypothesis. A single visualisation cannot fulfil any possible and contradictory demand at the same time. There are and there will presumably always be as many methods and designs for visualizing hypotheses as there are demands. These demands we consider as the main factors that influence the different methods of the visualisation of hypotheses. And we consider this as a need for the further development of the multiple states of the art. One of those methods we intend to present in this paper in the following.

The method that we have been calling the “visualisation of uncertainty” meaning visualizing hypotheses for more than ten years is our approach that we have been positioning against the so-called reconstruction of architecture since our first projects of mediating cultural heritage, Pergamon (Fig. 1) and Cologne Cathedral (Fig. 2). We introduced the term “visualisation of hypothesis” some years later when we realized that “uncertainty” is not always regarded as positive or even a neutral description of scientific knowledge.

The reason for the distinction of visualisation against reconstruction has been that in scientific communication, be it amongst scientists, between archaeologists and us architects, or by those museums and institution that go along with our approach towards the general public, the term reconstruction means to construct architecture a second time. Not only amongst building conservators, a real reconstruction, that rebuilds lost architecture a second time, is neither intended nor acknowledged. On the contrary, all participating sides are convinced that architecture that has been lost can never be reconstructed—and this not as a matter of exactitude but as a matter of professional ethos, both of archaeology and of architecture, since every building and every construction is always a product of its time, depending on building traditions, building rules and regulations and material issues. From this point of view, a reconstruction is neither desirable nor possible (see Rheidt, 2017).

*Fig. 1. Sanctuary of Traian in Pergamon (© Chair for Architecture and Visualisation); Video: http://www.pergamon.lengyel.info*

## Design

But other than usual and broadly expected, this does not have to lead to unambiguous color schemes. On the contrary, we and our cooperation partners from archaeology and building archaeology are convinced that the visualisation of hypotheses can preserve its character of being an architectural visualisation by the way of the most important traditional architectural representation technique, that is abstraction. So after the focusing from „visualisation of uncertainty" on „visualisation of hypotheses" we established a third way of describing our approach of visualizing hypotheses „design of abstraction".

The reason for changing the focus is that terminology is not only necessary for exchanging and establishing ideas, but also that information technology is a rather recent field of science and the junction of information technology, architecture, archaeology and building archaeology is even younger. The terms visualisation, simulation and animation are often used simultaneously and without distinction, especially when it comes to the exchange with exhibition designers, curators or even museum representatives. It might be a vision for the future, that at least in terminology the visualisation of hypotheses is clearly defined.

*Fig. 2. Cologne Cathedral around 1320 AD (© Lengyel Toulouse Architects Berlin); Video: http://cologne.lengyel.info*

For our demand to primarily visualize architecture, that by term includes architectonic structures but also architectonic planning and thinking, the design of abstraction is our way of including the visualisation of hypotheses and the visualisation of the architectural design, that is its original idea. The reason for this is analogue to the conviction that a reconstruction is neither desirable nor possible. It will presumably always remain impossible to discover the exact and detailed shape of a lost building. But there can always be a differentiated and scientifically well founded hypotheses about the intended appearance, that is the idea behind the building, its design and conception. And as every conception consists different degrees of abstraction, its visualisation means to give the abstract ideas—in most cases verbal descriptions—a concrete shape, an abstract formal, three-dimensional shape that needs to be designed, (see also Schwarzmaier et al., 2012; Stehkämper and Dietmar, 2016; Hauser and Loch, 2012).

Designing abstract representations of ideas means to create symbolic forms and shapes that suggest meaning other than their original appearance would in other contexts. This means that the overall composition of forms leads to the desired and intended interpretation. The decoding of the abstract forms depends on the skills in imagination, nevertheless the task is to find and use the most general and generic forms. The design of abstraction is a spatial version of the semiotics as described by Pierce (1986).

## Conclusion

There are many approaches for visualizing hypotheses that can be answered by an evenly large set of methods that one by one will develop itself in the future. For the demand to emphasize the architectural character of a hypothesis, the design of abstraction is our proposal of a direct translation of verbal hypotheses, (see also Deuring, 2016).

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# Hypothetical reconstruction of antique sculptures in colour

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***Keywords:*** *Mimesis—Zeitgeist—coloured variants*

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Our aesthetic perception concerning antique sculptures is enormously influenced by fading and dropping of pigments. The fragility of pigments makes it almost impossible to transmit the antique idea of coloured sculptures to those recipients who see themselves confirmed in their preconceptions about a monochrome-white antiquity.

Due to the strong presence of this monochrome manifestation of antiquity in mass media such as cinema films, series, video games and advertising, the acceptance of reconstructions of antique sculptures in colour is accordingly very low. Mario Bloier (2017) draws attention to the fact that even scientists are not immune to the power of “romantic images of the past” and of “beloved iconic images”.

The problem is profound. Not only that the risks will highly create an untrue image of the ancient world, it provokes fundamental changes in the aesthetic perception.

A hypothetical reconstruction of antique sculptures in colour can help to clarify this complex problem, since the taste of both, of the aesthetic effect and the antique colour are discussed. By means of colour reconstructions the essentials of *mimesis* are reflected not only on behalf of its well-known form but especially by the painting.

As a result colours have an enormous relevance for the interpretation of sculptures, or how Vinzenz Brinkmann (2017, p. 27) describes: “Color greatly increases the ‘legibility’ of a figure.” For example, Clarissa Blume (2015) explains that colours in Hellenism could be *local phenomena*: black was used only in Egypt for larger surfaces, in Italy earth tones were preferred and in Canosa even violet has a special status, while generally different pink and blue tones dominate the fashion, as for example in Fig. 1. This means that colours are not only a reflection of the epoch but also of site-specific traditions. Therefore, an art historical classification of contemporary aesthetic can help to create hypothetical reconstructions of antique sculptures in colours and accordingly illustrate the symbolic or mimetic function. Blume (2010, p. 255) writes in her conclusion, that “We should therefore not make it our sole aim to reconstruct the original polychrome appearance of the objects. The insights gained through the examination of polychrome decoration can also advance stylistic research, as well as

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allowing these sculptures to be interpreted more precisely with reference to cultural and social history. Colour does have a story to tell."

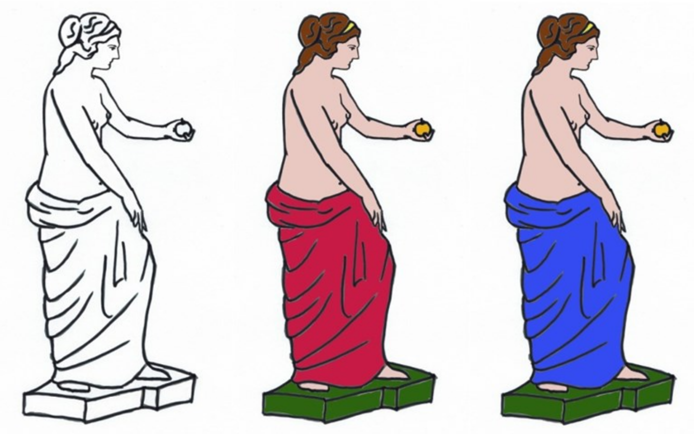

*Fig. 1. Reconstruction of Venus de Milo by Adolf Furtwängler in colour (© K. Mann)*

Due to the fact that hypothetical reconstruction in colour does not intent to illustrate an "authentic" image of an historical object, it would in fact generate an idea of *Zeitgeist*. This method could also be used to create coloured models of antique sculptures whose original colour version do not longer exist.

*Fig. 2. Reconstruction of Venus de Milo in colour (© K. Mann)*

Therefore, hypothetical reconstructions are of interest for those ancient sculptures, which are very important for our cultural memory, such as the Laocoon group, the Apollo Belvedere or the Venus de Milo.

History of Greek paintings, whose artistic innovations accompanied by political or social change, help us to obtain important conclusions concerning today's reconstruction of antique sculptures in colour. In this case it seems important to focus on new colours, theory of colours, modern painting techniques and painting styles, in order to get an idea of polychromy in the ancient world. Particularly remarkable are the differences between layer-painting and mixed-colour technique; these must be clearly marked reconstructing antique sculptures in colour. For example, it is essential to characterize the six-colour technique (layer-painting) on reconstructions of archaic sculptures where only the lower layer of colour can be identified. In this sense hypothetical reconstructions are enormously important, to avoid irritating impressions. It should be noted that each decision for a particular colour has an immense influence on the aesthetic effect and statement of the sculpture.

Digital Reconstruction Models should be preferred to casts (Fig. 2) in order to create variants of antique sculptures in different colours, thus to illustrate clearly the hypothetical character of the suggestion.

With this method, it is also possible to show modifications, for example by choosing a particular hair colour. The decision-making becomes even more complex through diverse possibilities of cloth colours, which communicate with the selected hair colour, like Fig. 3. Therefore, it is indispensable by hypothetical reconstruction of antique sculptures to involve the contemporary colour theory in order to make a selection.

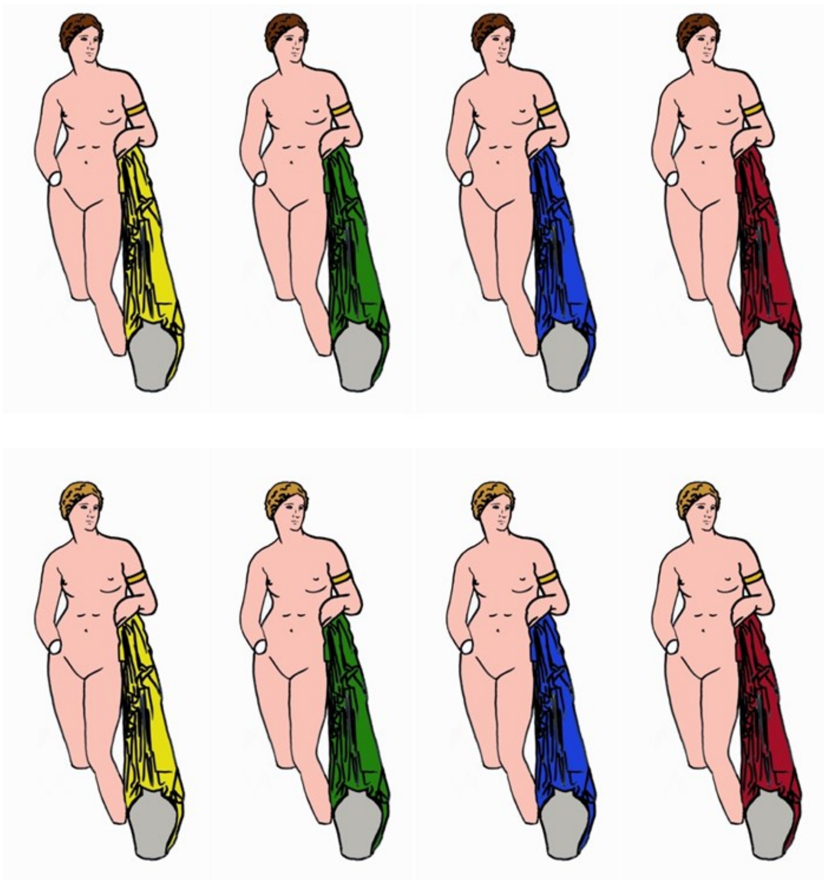

*Fig. 3. Reconstruction of Aphrodite of Knidos in colour (© K. Mann)*

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# Round Table:
# Digital Archiving: Questions, Problems, Examples and Answers(?)

David BIBBY | Christoph BLESL | Reiner GÖLDNER

## Digital Archiving: Questions, Problems, Examples and Answers(?)[1]

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Christoph BLESL, Federal Monumentum Board of Austria, Austria
Reiner GÖLDNER, Saxon Archaeological Heritage Office, Germany

***Keywords****: Digital Archiving—Backup—Selection—Cost effective*

There are as many definitions of “digital archiving“ as there are methods. When is archiving really “archiving” and when only a simple backup? Is one better than the other and if so, why?

There are a number of well-known digital archiving units specialized in the humanities, such as the Archaeology Data Service (ADS) in York, GB or the Data Archiving and Networked Service (DANS) in Den Haag, NL. These are well established institutions, but not the only instances of archaeological digital archiving practice. Everyone producing digital data is sooner or later confronted with the question of what to do with it. Which practices are in place? Are there some success stories? Do we all have common problems? Has the OAIS standard been widely adopted, or is a simpler system more widely preferred—such as simple, descriptive digital folder systems?

What, even, is the definition of “archiving”? Does it mean preserving the data for a predefined length of time? Or, should it always mean “permanent preservation”? Can we accept visual representations or do we have to preserve functions connected with the data? Permanent preservation meaning the inclusion of the necessary functionality/integrity/form needed to continue to keep the data meaningful, useful and accessible into the future. Which methods can guarantee continued usability?

Where is archiving taking place and what data is actually being preserved? What is selected for preservation and what is discarded? Are any guidelines in place to help make these decisions? What about low-cost archiving, what about less rigorous alternatives, are they safe enough?

This round table considered all these aspects (and more). In this round table digital archivists learned from each other’s experiences and hopefully receive new impulses for their important daily work.

[1] in cooperation with the Federal Monuments Authority Austria

# Digital Archaeological Archiving in Baden-Württemberg, Germany

## An Evolving System

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***Keywords:*** *Archiving—Data Structure—Data Formats—Archiving Practice*

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From the mid 1990s the Landesamt für Denkmalpflege Baden-Württemberg (State Heritage Department) has been collecting digital excavation and other project data. At first this sort of data—from the beginning of the "first" recording revolution was very much a novelty and in the minority. Most of the excavation data was still analogue and there was no awareness that the digital data might have to be archived differently from the paper record, which was simply put into a drawer and left to its own devices. Also, there was no "data discipline". No thought was given to formats. The approach was pragmatic: "Will this piece of software do the job? Yes? Then I'll use it". Only when data that had been "archived" on floppy discs or, later, CDs and the like began to degrade and/or no longer remain readable did it become apparent that steps had to be taken to prevent wholesale loss of irreplaceable data. The processed described below has been "learning by doing".

| Stage | Maturity Level | Description |
|---|---|---|
| Awareness | 0 – No awareness | The organisation has no awareness of either the need for the process or the basic principles for applying it. |
| | 1 – Awareness | The organisation is aware of the need to develop the process, and has an understanding of basic principles. |
| | 2 – Roadmap | The organisation has a defined roadmap for developing the process. |
| Capability | 3 – Basic process | The organisation has implemented a basic process. |
| | 4 – Managed process | The organisation has implemented a comprehensive, managed process, which reacts to changing circumstances. |
| | 5 – Optimised process | The organisation undertakes continuous process improvement, with proactive management. |

*Fig. 1. Archiving maturity Matrix after Adrian Brown, 2011*

After around 10 years of digital data collection a small project with limited resources and perhaps even less expertise was created to take stock of and deal with this dismal situation. This was the point of transition from “level 0” to “level 1” of Adrian Browns now famous archiving “Maturity Levels Matrix” from 2011 (Fig. 1). In the absence of access to dedicated archiving hard and software and knowledge a simple digital folder-structure with unique identifiers was planned and quickly implemented – “Maturity level 2”. This scheme became known as the “Rottweil Structure” (Fig. 2). Not because it worked like a guard dog, but because it was designed and agreed upon by a committee of archaeologists and technicians meeting in 2007 in the ancient Baden-Württemberg city of Rottweil. It has served as the basis for all further archaeological archiving work in Baden-Württemberg so far. Rather surprisingly the “Rottweil Structure” quickly received a wide acceptance—perhaps because it reminded fieldworkers of their own system of folders on shelves and they could relate to it. First thoughts were also had about data formats and the actual meaning of “long term digital archiving”. The Landesamt für Denkmalpflege’s definition of “long term” quickly became “forever”, bringing with it all the consequences of eternal readability, access and functionality of the data—through… Emulation? Migration? Or what?

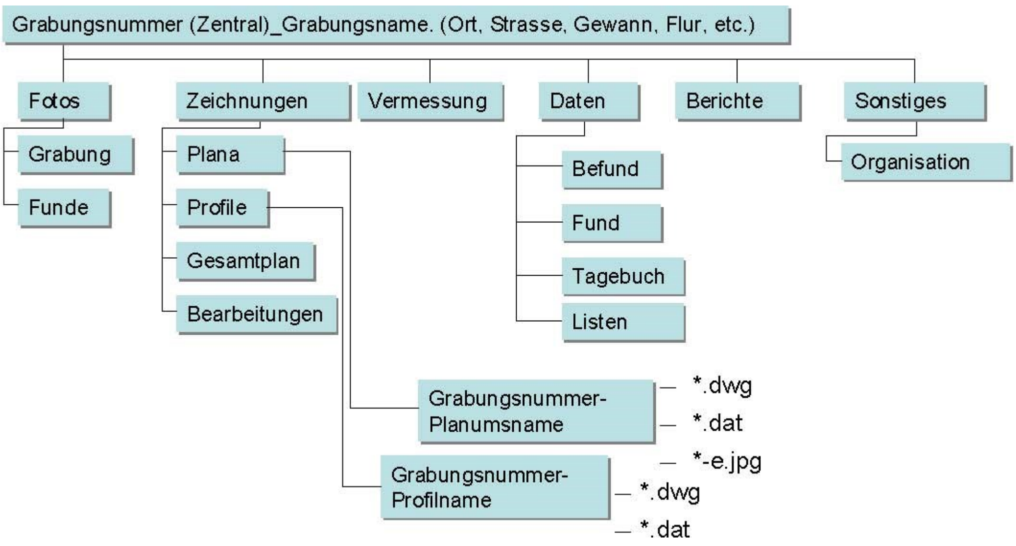


*Fig. 2. The “Rottweil Structure”*

By 2011 the problems had become further compounded by questions as to the archivability of CAD-data, which had up to that point been a mainstay of excavation documentation. Two further factors made the situation even more acute: The change of licensing terms by large proprietary software firms and the shift from 32 bit to 64 bit computer systems. The price of updating the software in use at that time was prohibitive. This challenge was, however, also an opportunity, an opportunity for a number of paradigm-shifts: Away from software limited research to research driven software, away from expensive proprietary software to real open source solutions and (more) open data formats. In a process lasting more than half a decade the transition was made away from CAD to GIS as the mainstay of project recording in Baden-Württemberg. The development of the Software Survey2GIS (GNU GPL) facilitated on the one hand an easy to use transition of field data into GIS and on the other better control of data formats. The addition of increasingly more laser scan, LIDAR and sfm data and the advent of commercial archaeology in Baden-Württemberg made it necessary to revise the Rottweil Structure to firstly, cope with the ever increasingly complicated data-world and secondly, to standardise the data sets produced by commercial archaeological companies in the State (Fig. 3). Thus also enabling the State to define acceptable and archivable data formats.

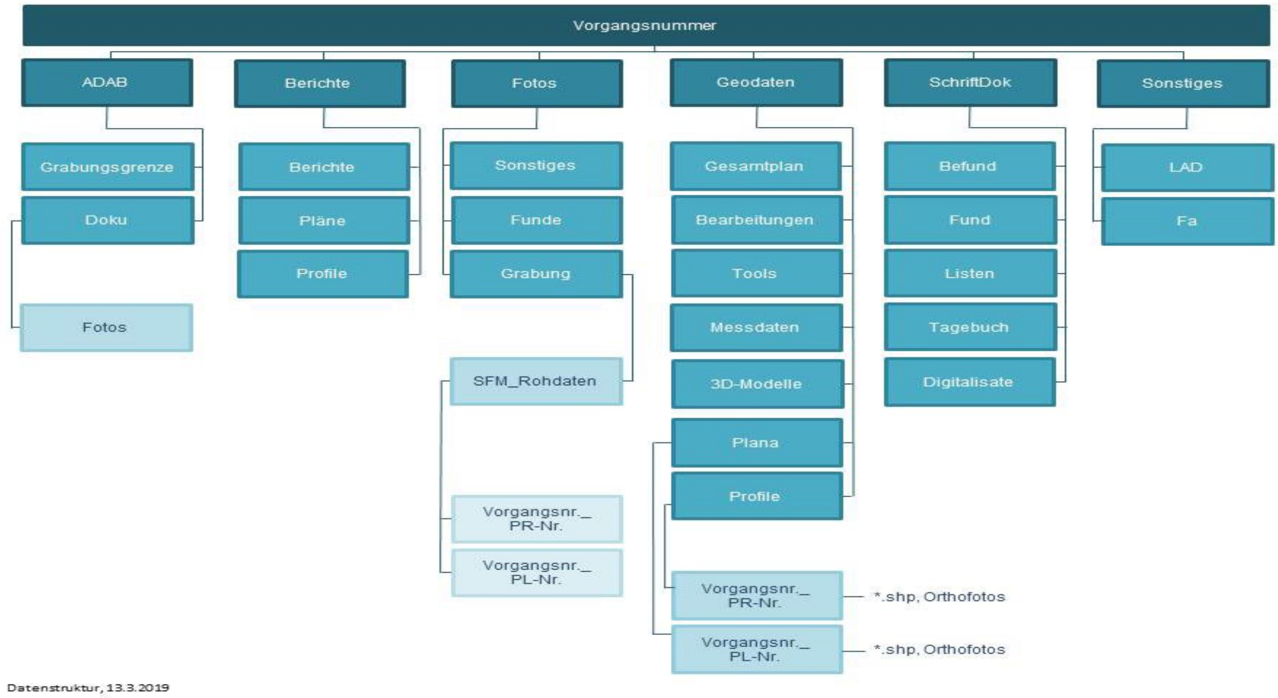


*Fig. 3. The present Data Structure*

One of the stiffer jobs over the last years has been convincing archaeologists, technicians and ancillary staff that it is necessary to securely save their data in a central repository. Now this concept has received wide acceptance—especially after workers have experienced the possibility to recover "broken" data from the archive! At present the excavation archive contains tens of terabytes of data appertaining to around 4000 projects in Baden Württemberg, hosted on secure State-owned servers. Content lists are published regularly. The acceptance of the system and cooperation from all sides has meant that it has now been possible to take a first step away from a simple data-hosting repository toward a usable and accessible archive. Limited excavation/project data can now be uploaded to the State's own cultural heritage GIS-Application—ADAB—where it can be accessed by researchers. Each polygon representing the extents of an excavation/a project is linked to metadata with a short report and a selection of informative photos so that pertinent information can be quickly gleaned on each project (Fig. 4).

The excavation archive in Baden-Württemberg is not yet a fully accessible, usable "real" digital archive. But it has succeeded in saving the data for the transition into that "real" archive The maturity level after Adrian Brown is just at the start of "level 3". Hopefully this short description of the progress of the digital excavation archive in Baden-Württemberg is of interest to others concerned with digital archaeological archiving. The archive managers from Baden-Württemberg would most certainly welcome an open and honest exchange of information and transfer of knowledge on this crucial issue.

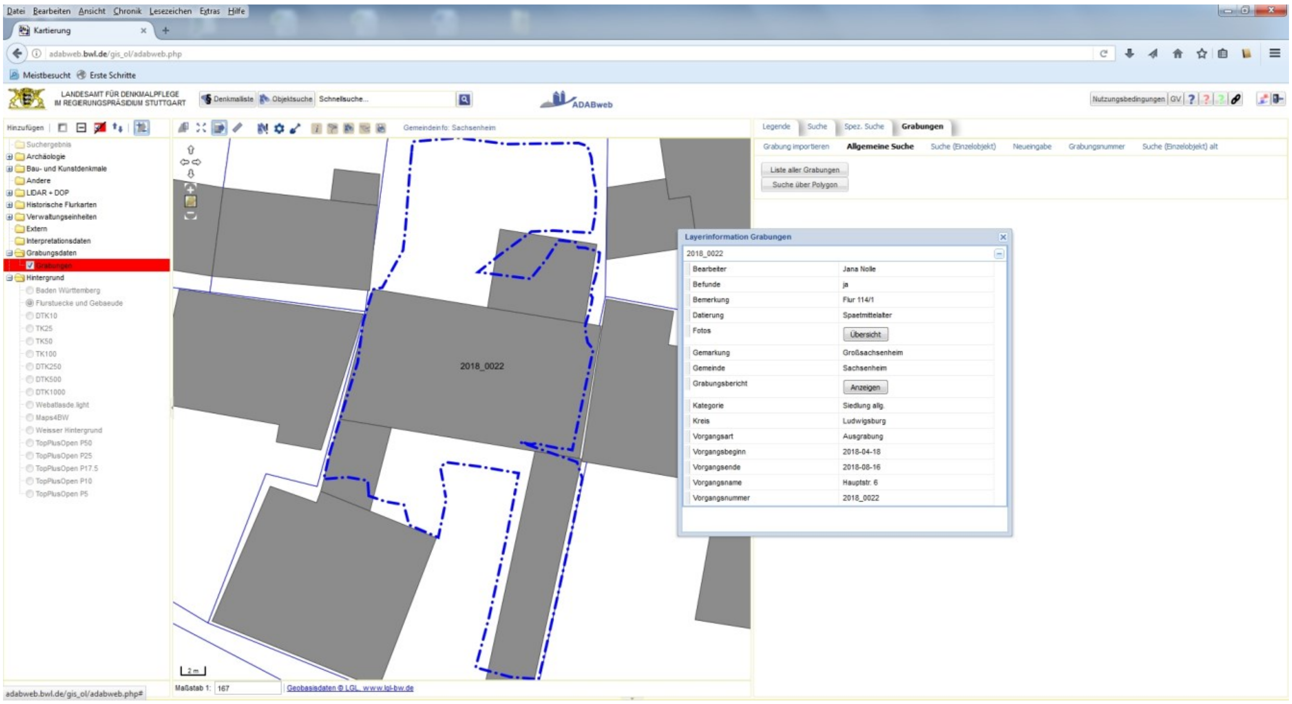


*Fig. 4. Excavation extents in ADAB-GIS*

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# Digital Archiving with the database application PGIS

## Developing concepts to model archaeological data

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***Keywords:*** *Digitalisation—GIS—Database—Archive*

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doi: 10.11588/propylaeum.747.

## Expert information system for cultural heritage in Rhineland-Palatinate

It is the task of the General Department of Cultural Heritage Rhineland-Palatinate (GDKE Rheinland-Pfalz) to preserve cultural monuments. In 2018 a digitalisation strategy started in order to provide data without media interruptions. It aims to digitalize workflows and the emerging media. With the foundation of the GDKE the state department inherited multiple database collections, which were to be consolidated and prepared for further use in the centralized database application PGIS (Himmelmann, Schuppert et. al., 2013). It manages metadata, geodata and media of all six directorates of the GDKE (Department of State Archaeology, Department of State for Monument Conservation, State Museums in Koblenz, Mainz and Trier Rhineland-Palatinate, Administration of Palaces)

During the development process it was the aim to rely on open-source software wherever possible. The advantages are reduced costs of licence purchases and the freedom to develop custom needs in the used software itself. The general conditions in the GDKE are based on a windows domain network and Microsoft Office integration.

In this abstract we want to focus on the implementation of the archaeological part of the PGIS application. It concludes data from excavation sites to inventory items in depots. To fulfil the legal requirements of the GDKE it is possible to designate special protection areas and publish statements to institutions of public issues. It is the objective of the database to create a dataset which links metadata, geodata and media. This results in a searchable archive.

### Components and Structure of PGIS

Considering the combination of multiple data formats in metadata, geodata and media makes the need for different techniques obvious. The structure consists of the following components (Fig. 1):

- **MSSQL Server** stores the data of the specific objects with their description and is also able to create reports in PDF and the common Microsoft Office formats xlsx and docx
- **PostgreSQL** Server stores geospatial data

- **Mapserver** handles publishing spatial data as Web Map Services (WMS)
- **Mapbender** and **OpenLayers** are both frameworks for the display of maps in a Web-browser and in the PGIS application
- **QGIS** is the Desktop GIS used for creating geodata of the objects
- **Visual Studio .NET** for the GUI development and programming language

Using the advantages of a modular system, the departments can define their own data model including describing fields, thesauri, etc. (resulting in forms like Fig. 2). In a following process they can participate and influence layout and workflow.

PGIS functions as interface between all the above-mentioned techniques. Starting from the dataset the user can create a geometry via QGIS and publish it in advance. For publishing there are several possibilities. The Geoportal RLP is a geodata infrastructure (GDI) regarding all data of Rhineland-Palatinate. An interface between PGIS and the GDI exists which enables data exchange. Further PGIS can extract data into various export data types including XML, CSV, HTML, Microsoft Office Documents and supports exchange formats like ADeX (Himmelmann, 2008). Therefore, PGIS is the central control element to create a dataset which describes a real-life object.

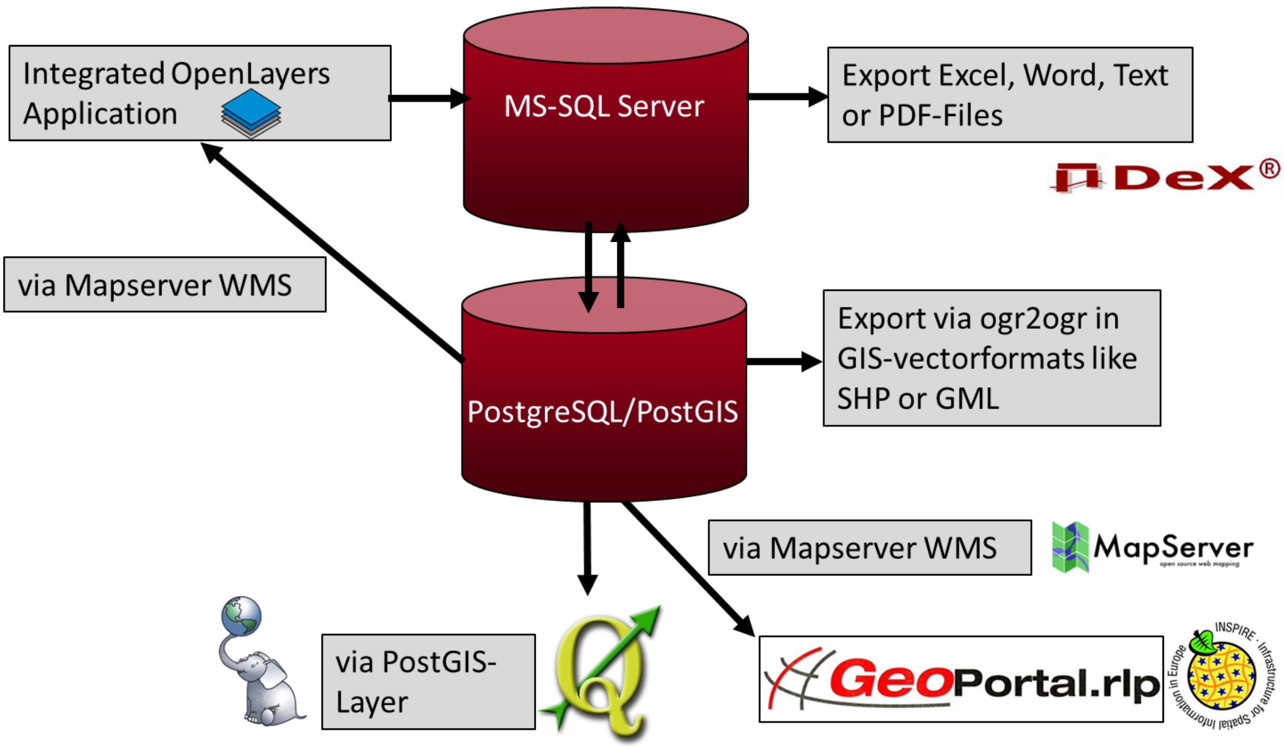


*Fig. 1. Structure of PGIS components (© GDKE)*

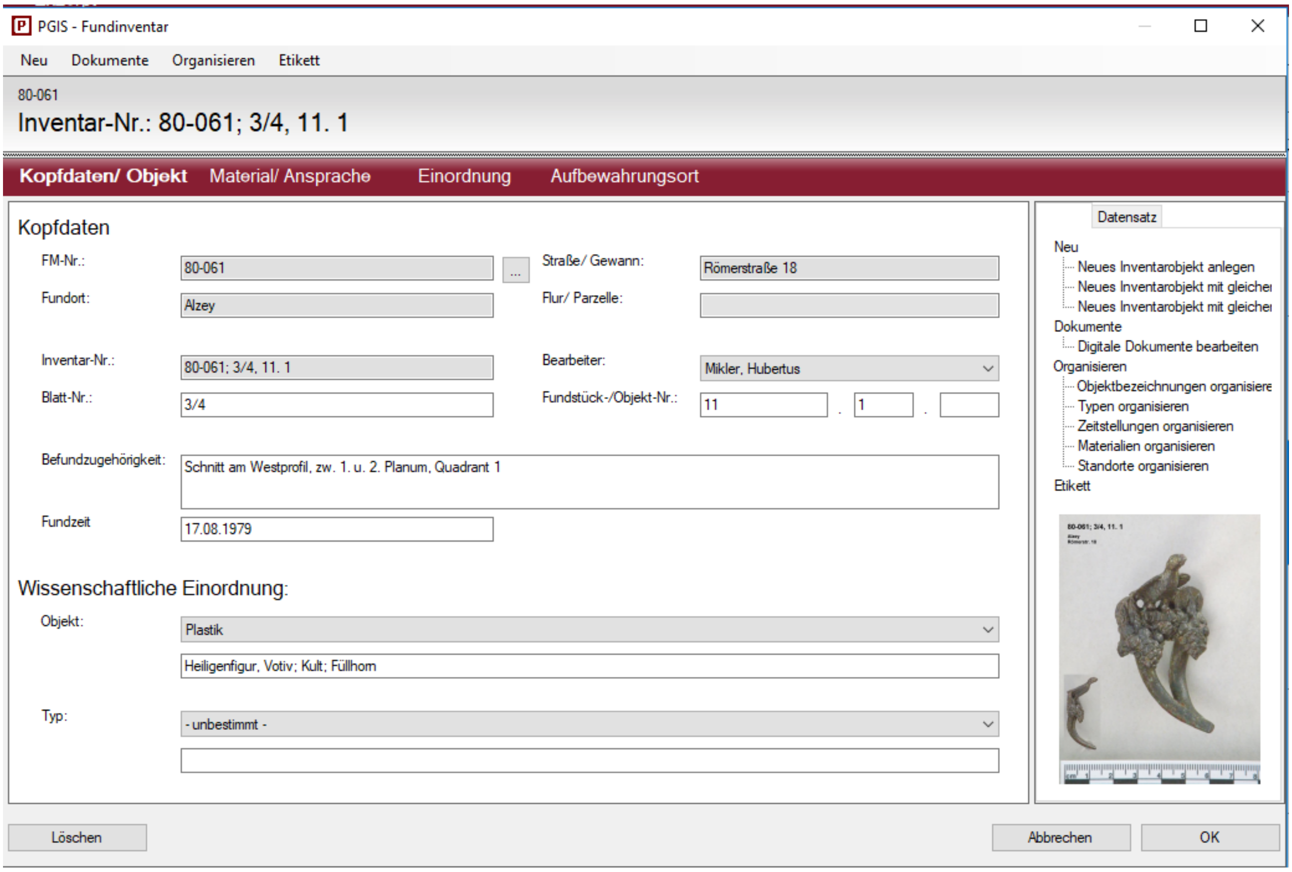


*Fig. 2. A PGIS dataset linked with an image of an inventory object of the archaeological department Mainz (© GDKE)*

## Handling of media and archiving in PGIS

Every dataset offers the possibility to store files within. In PGIS exists a well-defined list of file-types with the aim to ensure long term usage. Based on the work of Bibby, Brunn et. al. (2011, pp. 15ff), data types are divided in three levels which are adapted by PGIS. For text information TXT and PDF/A are considered preferred, in terms of image files the format of uncompressed TIF is considered as preferred and compressed TIF and JPEG are considered accepted. Given the general conditions of the GDKE MS Office Documents are used for the major part of exchange and therefore required to be part of the list. The upward compatibility of MS Office data formats allows to update documents in a regular process (e.g. doc → docx). In the process of linking a file to a dataset the file is copied to a storage system. By accessing, the file is copied to a temporary folder on the machine of the user. Any changes only affect the copy. In case of uploading, a new file is created and the original stays untouched. Therefore, all files managed by PGIS are change proof and can be considered as 'archived'.

A major part of files are images, which are formatted to serve several purposes: the original is stored, one additional image gets rendered to a lower resolution for digital display, another image gets rendered as a thumbnail preview. Therefore, the network traffic is reduced. For each dataset the user can select one of the existing images as most representative which is shown as 'title picture' (Fig. 2).

For future development it is aimed to enrich images by exporting text information from the database into the metadataset, for example storing the name of the shown object into the image file. Based on this information other applications like an image archive software can read the metadata and allow to categorize and create structures based on the information from the entries made in the database. Further it is planned to offer a possibility to connect one image to several datasets, which reduces redundancy of storing images.

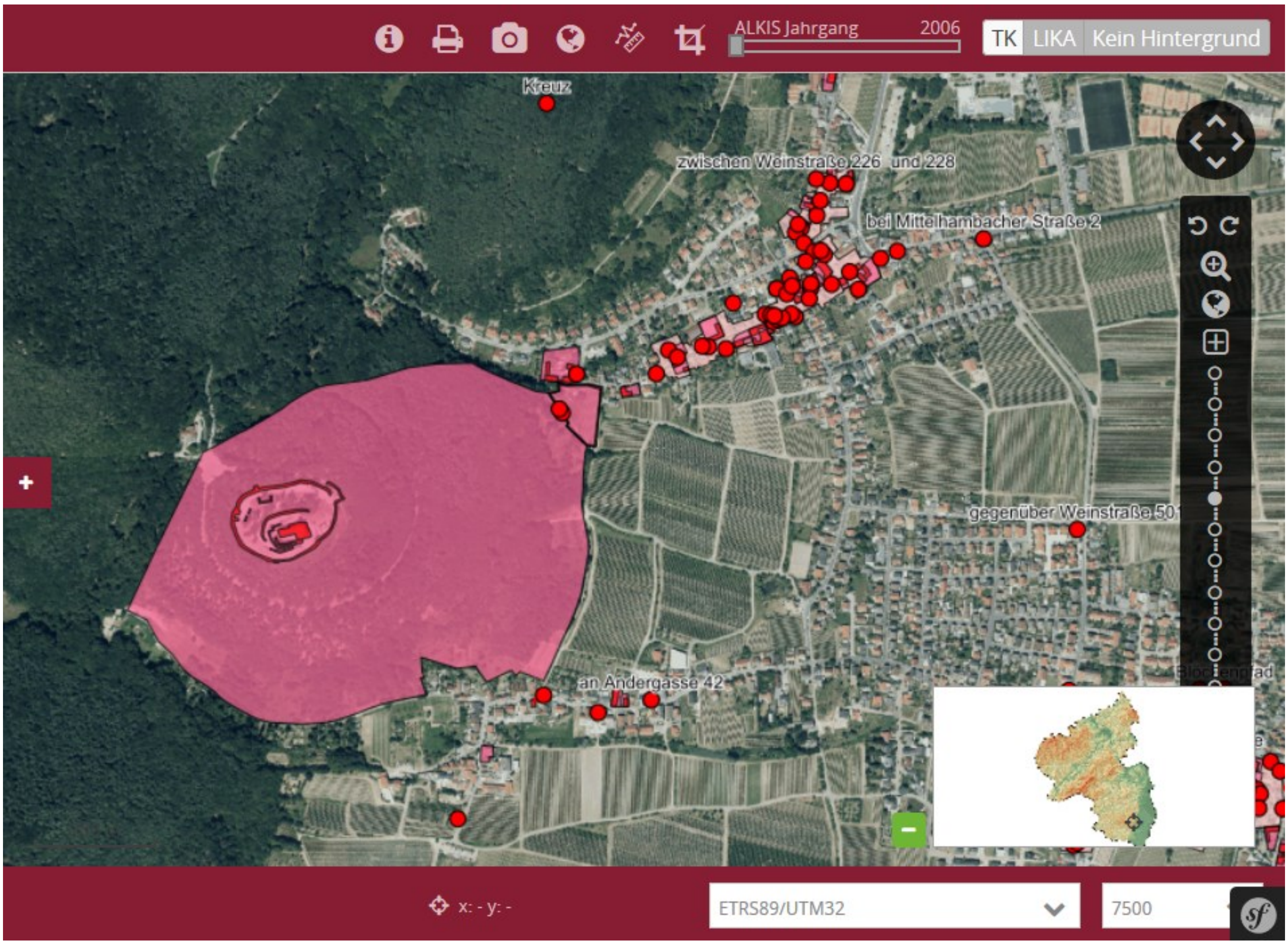


*Fig. 3. Mapbender customized for use in GDKE displaying cultural monuments of Neustadt an der Weinstraße (© GDKE)*

## Geodata Infrastructure in PGIS

With the technological advancements in the recent decade new possibilities for digital mapping emerged and found its way in the working processes of archaeologists. In PGIS this process developed from basic notation of numeric point coordinates to a complete geodata infrastructure.

The framework Mapbender as well as OpenLayers play major roles in the interactive exchange of information. Being able to display information on a map offers various possibilities. Sharing information about sites between departments improved the harmonized output of public statements. The development of other institutions resulted in a diverse supply of data which improved the quality and precision of information and evaluation possibilities. For this purpose, both frameworks are able to import WMS and Web Feature Services (WFS) as Layers. In addition, Mapbender offers the implementation of customized search queries. For example, requested parcels in a public statement can easily be found, and combined with layers of the departments (Fig. 3). The dimension handler element enables the Mapbender-application to overlay maps of different years in order to produce a timeline. Therefore, the user can observe the change of the landscape over time in dependency of the site.

## Conclusion

Based on the development of PGIS it became apparent that the topic of digital archiving can be interpreted as a process depending on three aspects: management of data, requirements of the GDKE and technical advancement. All of them are in constant change. Storing data in databases (PostgreSQL and MSSQL), media in file storage systems and using logic in form of PGIS application to connect both enables dynamic reaction to change in any of the three aspects. Advances in new technologies can be integrated and changed comfortably. The exchange and constant communication with others provide improvements in the process of adopting to the changing circumstances.

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# Archiving by Analogization!?

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***Keywords:*** *digitalization—analogization—archaeological documentation—archiving*

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doi: 10.11588/propylaeum.747.

We love digitization because we live in a digital world. Information technologies (IT) help us to tackle complex affairs like never before. Bookshelves, photo albums, worldwide maps, excavation documentation available at about 100 grams of IT, as is intelligent interpretation of handwriting as well as voice and face recognition. No problem. Archaeology too benefits greatly from such digital methods. High resolution 3D-scans from archaeological objects are created, examined, analyzed and published, as can be seen at the “archaeo | 3D” website (LfA-SN, 2020).

However contemplating sustainability, preservation and things that remain, the chances for digitized objects are not that good. Digital life is short and it takes much effort to archive digital content and especially digital functionality. Often it is too expensive. Often there is no spare capacity for the preparation and curation of archive material. So, mountains of digital data grow and grow, waiting to be excavated by future digital archaeologists.

Though contemplating cognition, creativity and our real world interaction, bits and bytes are usually not helpful, analogue information is needed. People read analogue texts, study analogue images (on-screen) and listen to analogue sounds. Especially scientific reasoning will continue to be a non-digital method (even though artificial intelligence seems to expand into refrigerators and washing machines). So digitization needs analogization (Fig. 1).

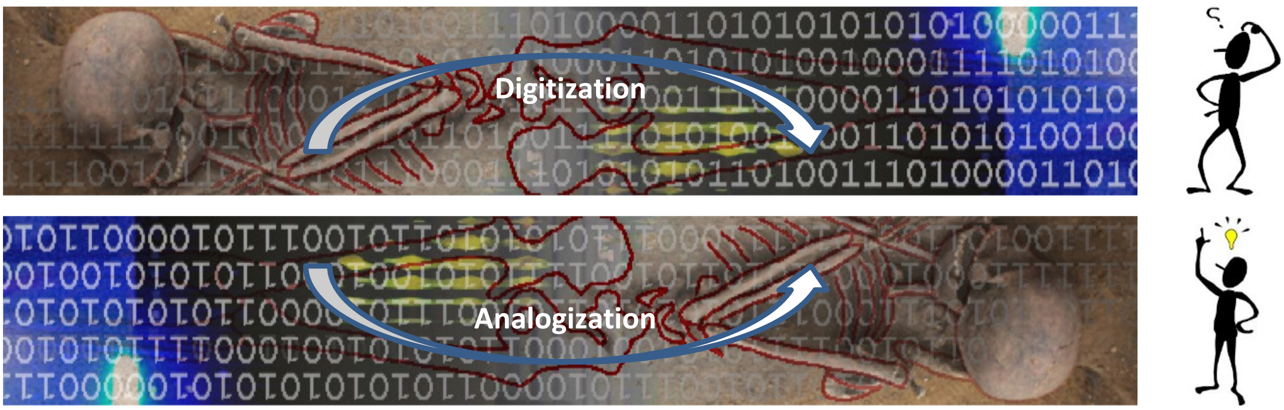


*Fig. 1. Digitization needs Analogization. (© R. Göldner)*

Archaeologists, especially, are familiar with lots of analogue things that survived thousands of years (without any curation effort). Some archivists also try to preserve digital information in an analogue form, as hardcopy maybe on/in LE paper, PET microfilm (Göldner, 2012) or ceramic tiles. The major advantage is: these archive materials are directly readable (recognizable), without any help of IT. Let's consider two examples. The "Rosetta Stone" (Fig. 2) is more than 2000 years old, its inscriptions has been visible very clearly with the naked eye until now and its life cycle has a very good prediction. The "Memory of Mankind" (MOM, 2018) tries to use ceramic tiles with engraved texts and printed images (ceramic colors) to save information e.g. from books, news articles or private documents. The tiles can be read by eye with 10x magnification. They are archived deep in a salt mine at Hallstatt (Austria) and the location of this archive is published by ceramic tokens (Fig. 3) with an engraved schematic map, that can be spread as wide as necessary. MOM wants to preserve stories of our time on most sustainable analogue media saved deep in the mountain.

*Fig. 2. Part of Rosetta stone (source: Rosetta 2019)*

So one may hit on the idea of omitting all the IT. Wouldn't it be cheaper to draw excavation plans on paper than digitize it first and print it out last? Wouldn't it be more authentic to draw a plan directly by hand then to trust hidden data exchange of bits and bytes?


*Fig. 3. Ceramic tokens from the "Memory of Mankind" MOM (source: Token 2018)*

Here are some ideas to answer these questions. Consider the whole working process starting with analogue information and ending with analogue information. Consider the whole digital process starting with digitization, including analogization and (never) ending with frequently renewal of hard- and software and especially with ongoing and costly curation efforts. Consider the drawbacks of a non-digital process, especially the loss of functionality (no order, filter search function, no links, no internet publication, no complex analysis, no complex statistics and so on). Comparing all the results it cannot be ruled out that a non-digital method will top the IT but this will be solitary cases because a broad functionality is usual and it is expected.

Some interested professionals discussed this provocative idea at the workshop on “Digital Archiving” (CHNT 24, Vienna 2019). They agreed that analogization can be an effective way of archiving, especially if an analogue representation is sufficient and if there are special circumstances that are contrary to an appropriate digital archiving (e.g. lack of resources). But, in kind of “real” digital data that supports digital content and digital functions, there is no way around active digital preservation with all steps known from the OAIS reference model (OAIS, 2019) especially Data Management and Preservation Planning).

The résumé is: analogization may be helpful to archive special content but normally an appropriate digital archive is needed to preserve digital data for a long time.

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# The lifecycle of pottery data[1]

## A case study in archival practice

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Laura REMBART, Austrian Archaeological Institute of the Austrian Academy of Sciences, Austria

***Keywords:*** *pottery—legacy data—archiving—archaeology—accessibility*

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doi: 10.11588/propylaeum.747.

## Introduction

A recent project in Aswan, Egypt, resulted in the discovery of an exceptionally large number of pottery fragments. While the large quantity of pottery in combination with the stratified contexts was seminal to the study authors in gaining more detailed insights into the commercial and social life of the inhabitants of Hellenistic, Roman and late antique Syene/Elephantine than expected, it also resulted in considerable problems regarding the publication of the data and the management of such large amounts of information.[2] Throughout the project, the pottery had been processed according to a consistent workflow that included the quantitative assessment of all pieces and the detailed documentation of all diagnostic pieces which were entered in an MS-Access database that was originally created for the documentation of pottery in Ephesos in 1998 and had since been slightly adapted (Kerschner et al., 1998). In order to publish the entire database of 16,000 diagnostic sherds it was necessary to seek out new and digital forms of publication since the number exceeded what could sensibly be published in a traditional format. Furthermore, the database had been created in an outdated mdb-format and it was necessary to secure the data in its entirety.

Through the FWF-funded Open Research Data project “Wares, Types and Fabrics. The Upper Egyptian Contribution to the LCP”[3] the pottery data collected in the MS-Access database was entered into the open access pottery database of the Levantine Ceramics Database (Levantine Ceramics Project [LCP]; https://www.levantineceramics.org/). The goal of this project had been to upload the original database to the LCP, however, several issues arose in the upload process and necessitated a re-evaluation of the data lifecycle of pottery data and an adjustment of the online publication strategy in order to remedy the issues. Instead of uploading the pottery data to the LCP in its entirety, only the most important pieces were uploaded (ca. 2,500 entries) along with entries on all wares and

[1] This short paper is published under the Creative common license 4.0 (CC BY-SA 4.0)

[2] See also High-Steskal et al. 2017. On the study of the pottery see: Rembart, 2018; Katzjäger, 2017; Peloschek, 2015; for a full list of publications on the site, see High-Steskal, 2019a.

[3] FWF ORD 69; project led by Sabine Ladstätter; based on FWF project P 23866 “Housing in Antiquity in Syene/Elephantine, Upper Egypt.”

petro-fabrics, in addition to accompanying photographs, thin section photographs, and drawings. Additionally, the entire original MS-Access database was exported to Excel, cleaned with Open-Refine, enhanced with additional information and cross-linked with the corresponding information in the LCP and other data to increase both their findability and interoperability. These lists represent the complete pottery record and are currently in the process of being curated and prepared in a sustainable data format for upload to ARCHE, the digital archive of the Austrian Academy of Sciences.

## Guiding Principles

As a result of this experience, a guideline for working with pottery data at the Austrian Archaeological Institute was created so that future projects can avoid detours made in earlier projects and support colleagues in developing data management plans before they begin their projects (High-Steskal, 2019b). The following four rules adapted from the FAIR principles govern the guidelines:

1. Document everything (individuals involved, publications and talks connected to the data, short descriptions of steps taken in workflow, create concordance lists…) so that the metadata fields can be created as precisely as possible.
2. Be consistent and transparent (terminology, language, file types…) so that the data is not marred by errors.
3. Contextualize data (link to chronology tools, gazetteers, other pottery databases…) so that the data becomes findable to other people and machines.
4. Make data reusable (what information do users need to understand dataset? Can data be downloaded? Have clear standard licenses been formulated?). Reuse increases the value of data and the importance of the scholar who created it.

During the creation of the guideline a conscious decision was made against using technical jargon and in favor of formulating the necessary steps in as much detail as possible while highlighting the benefits of curating data for long-term preservation. The reason for the level of detail in the guideline was to help all researchers, especially the less confident computer users.

In addition to creating more awareness for data management and the need for archiving research data, it was also necessary to engage in broader discussions on the data life cycle with colleagues. To a certain extent, curation and archiving processes still hold an uneasy place within our field because they have not yet been accepted as a serious form of scholarly output (Sobotkova, 2018, p. 117). This is expressed, for example, in the inability to list archived datasets in departmental databases that monitor scientific output or also the lack of acceptance for listing most forms of digital contributions in official CVs.[4]

[4] The American Institute of Archaeology recently published the following recommendations under the heading ‘Guidelines for the evaluation of digital technology and scholarship in archaeology’ here: https://www.archaeological.org/programs/professionals/careers/tenure/ (Accessed: 21 August 2019).

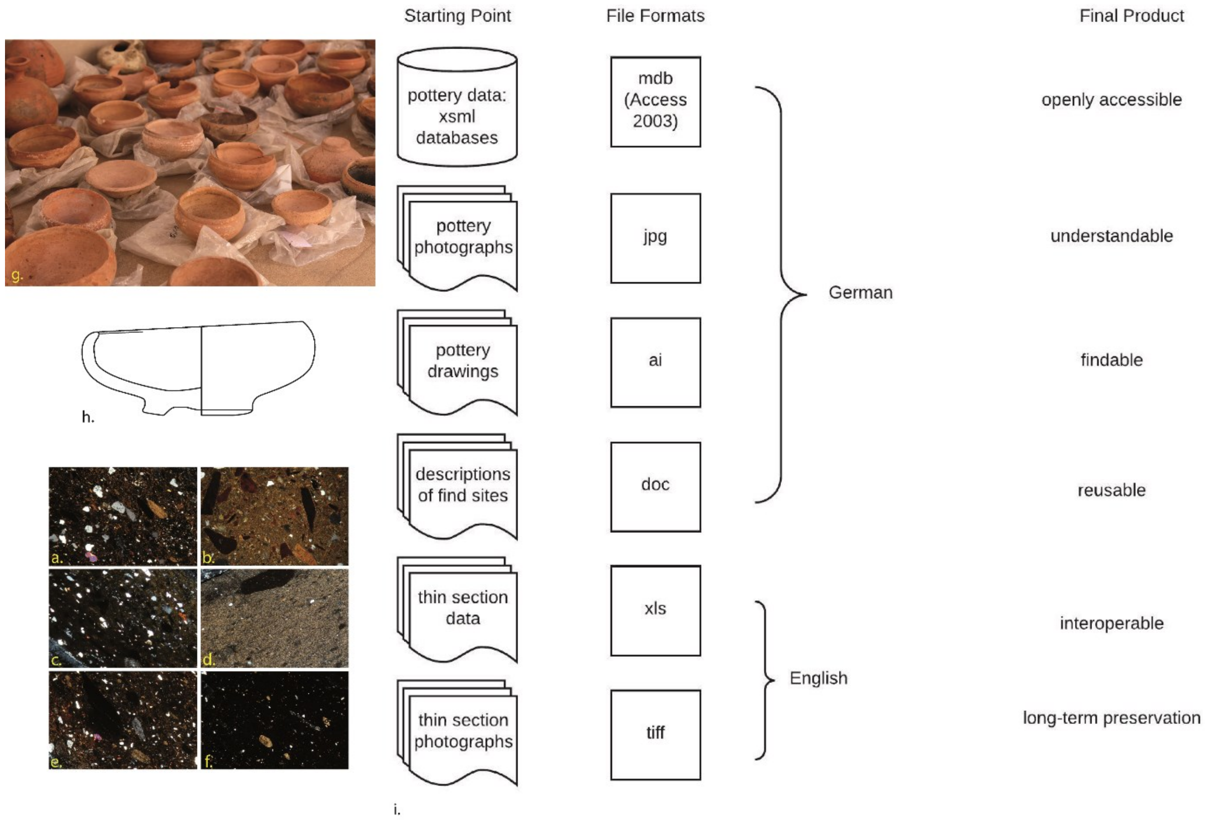


*Fig. 1.a-f: thin section samples of pottery from Aswan (© OeAI-OeAW/Lisa Peloschek); g: pottery from Aswan (© OeAI-OeAW/Niki Gail); h: pottery drawing of Aswan material (© OeAI-OeAW/Laura Rembart); i: data types and formats created while processing pottery from excavations in Aswan (© OeAI-OeAW/Nicole High-Steskal)*

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Encouraging archival practices among scholars more broadly requires a multi-pronged approach: educating all individuals on methods and issues in archiving their digital data; including data stewardship as an important aspect of the research process; and accepting archived datasets as valid scientific output of researchers.

[5] The American Institute of Archaeology recently published the following recommendations under the heading ‘Guidelines for the evaluation of digital technology and scholarship in archaeology’ here: https://www.archaeological.org/programs/professionals/careers/tenure/ (Accessed: 21 August 2019).

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# Round Table:
# 3D Excavation Geodata and GIS

Reiner GOELDNER | David BIBBY

# 3D Excavation Geodata and GIS

Chairs:
Reiner GOELDNER, Saxon Archaeological Heritage Office, Germany
David BIBBY, Regierungspräsidium Stuttgart, Germany

***Keywords:*** *3D excavation documentation—3D GIS—3D analysis—sustainable preservation*

There is no archaeology of large urban and underground infrastructures without 3D fieldwork geodata.

This round table dealt with 3D excavation geodata and its computational use. Meaning the creation of 3D geodata in the field, as well as the scientific analysis of such data. The use of geographic information systems (GIS) with 3D capabilities was a central aspect of this round table.

3D fieldwork records, geodata and GIS seem to be a harmonic trio, but there are some practical problems. "Traditional" digital fieldwork records are created with total station and CAD software—and CAD offers real advantages for 3D data. On the other hand CAD is not good in dealing with attributes. The attribute problems may be solved by using geodata and GIS, but 3D GIS is expensive and so far FOSS GIS does not offer adequate 3D features. For the collection of 3D field data FOSS tools like "Survey2GIS" or "TachyGIS" can be used. But are there alternatives? And how can this 3D data be adequately displayed in GIS?

Alternative 3D measurement methods such as laser scans or SfM allow fast workflows and gather large amounts of 3D data. But are they well adapted to archaeology? How might we adequately exploit the potential of this 3D data now and how can we analyze it in a scientific way? Which geodata structures and types are best suited? How can we provide permanent access to it over years and years?

We discussed archaeology-driven software requirements for the development of adequate 3D GIS tools. We discussed brand new archaeological analysis methods for dealing with 3D geodata. It was a practice-oriented exchange of experience on 3D documentation of archaeological excavations—both the methods and consequences.

Survey2GIS. online: https://www.survey-tools.org

TachyGIS, online:

http://www.landesarchaeologen.de/fileadmin/Dokumente/Dokumente_Kommissionen/Dokumente_Archaeologie-Informationssysteme/Dokumente_DGD-WS/V_Goeldner1_TachyGIS_Artikel.pdf ]

- archaeological excavations (rescue excavations, …)
- 3D measurement and documentation
- survey and analysis
- geodata types and structures
- strategies for sustainable preservation of archaeological geodata (content and function)
- paradigm shift from CAD to GIS

- practice-oriented exchange of experience
- FOSS
- Survey2GIS (that supports transformation from offline total station data to geodata)
- TachyGIS (that shall be able to input 3D measurements online from total station to GIS and to provide an adequate 3D monitor).

# The Ongoing Development of Survey2GIS and the potential of Free and Open Source GIS for Data Collection and Analysis on Excavation

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***Keywords:*** *GIS—FOSS—Excavation—Recording*

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doi: 10.11588/propylaeum.747.

The potential of Free and Open Source Software (FOSS) is still to become fully recognised in archaeology. In one area, GIS, FOSS is readily available for productive use. Recently, the high costs of replacing outdated commercial software, hardware and operating systems used for basic and essential archaeological recording and surveying and changes in proprietary licensing models have become a catalyst for the movement toward FOSS. In the case of the Landesamt für Denkmalpflege Baden-Württemberg (State Cultural Heritage Department, Baden-Württemberg) the ongoing development of Survey2GIS, a light-weight FOSS tool for use in field documentation and surveying, a sustainable program for transferring survey data into GIS.

Survey2GIS is a flexible and user-friendly, cross-platform open-source tool, capable of processing raw survey data and converting into topologically cleaned GIS datasets. It is a fully developed, compact and flexible solution for handling topographic survey data. It is capable of processing 2D or 3D point measurements into complex geometrical objects (points, lines and polygons), including multipart features and incomplete polygons. The output generated by Survey2GIS is ideal for direct use in GIS (at present QGIS is in wide use in the Landesamt für Denkmalpflege Baden-Württemberg). Input data consist of one or more survey data files with coded coordinates. These data can come from a variety of sources: data collected in the field using, for example, a total station or GPS device, lists of coordinates or even pre-existing cadastral files. Output data is in the form of the widely used ESRI(tm) Shapefile format (2D or 3D), according to geometry type and with complete automatically created attribute data.

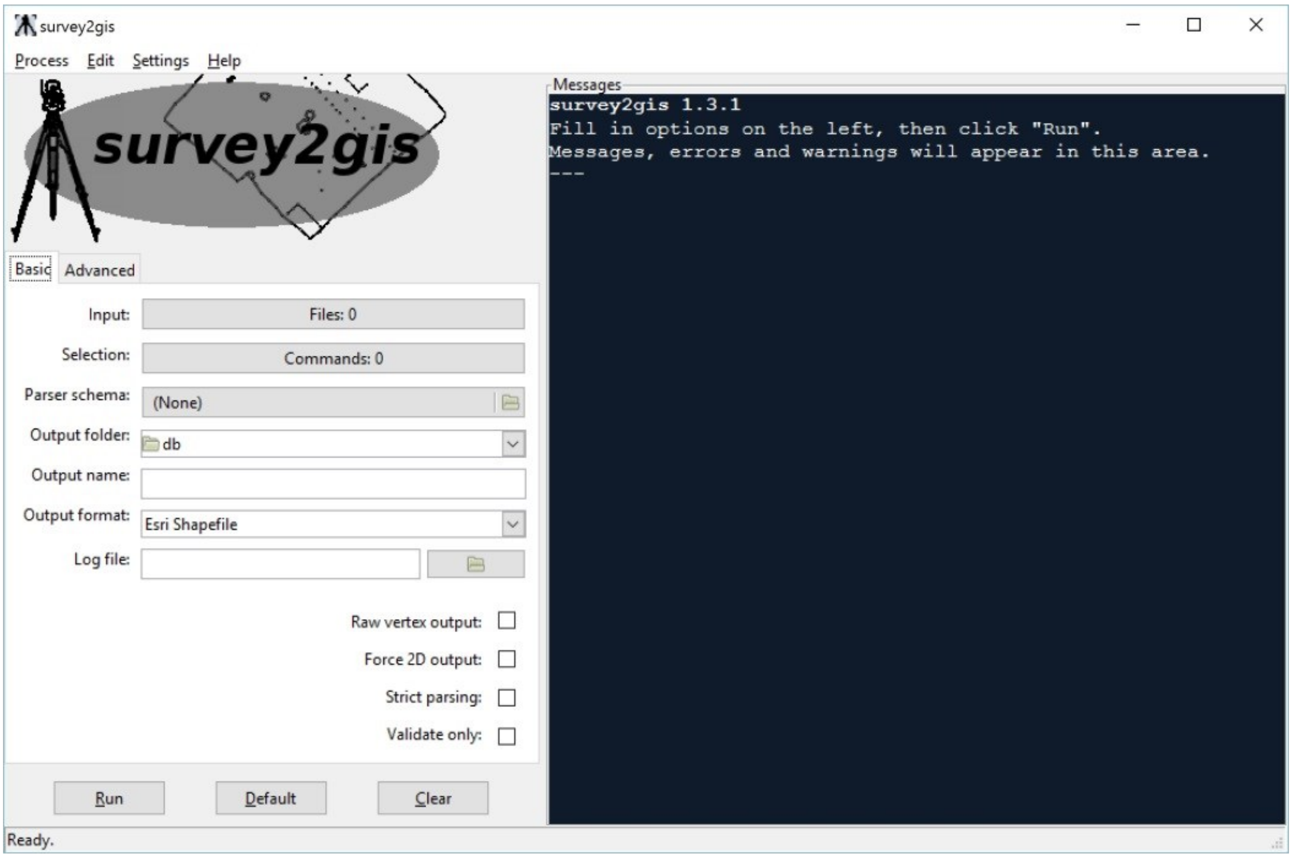


*Fig. 1. Survey2GIS GUI*

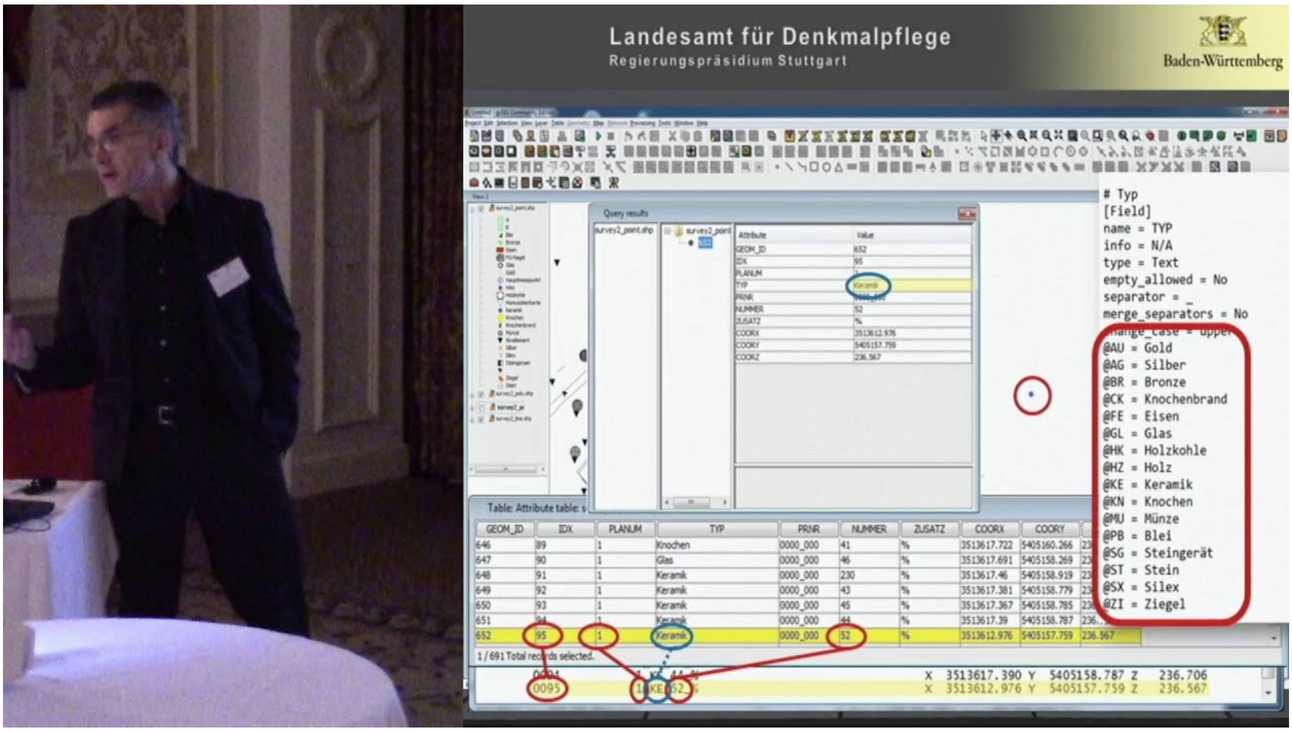


*Fig. 2. The creation of Attribute Data with Survey2GIS-Thesauri.*

This process can be fully controlled by the user, thus allowing flexible adaptation to individual survey workflows and data structures. The software is user friendly, easy to learn and feature-rich, with detailed procedures to support quality assurance and consistent documentation of all processed data. Special attention has been given to the needs of archaeologists in the field: For instance, Survey2GIS enables the “misuse” of GIS to create sections as well as automatically creating section lines in the plan.

The most exciting development of the last twelve months has been increasing exploitation of survey2GIS’s simple scripting system allowing data-driven, rather than program-driven, input and output. Input and output formats can be adapted to fit the requirements and constraints of virtually any project. During its development, high priority has been given to the generation of topologically correct output, suitable for quantitative analysis in GIS. It was important from the outset that Survey2GIS should not depend on other programs in order to run. Therefore, Survey2GIS is fully functional as a cross-platform, independent stand-alone.

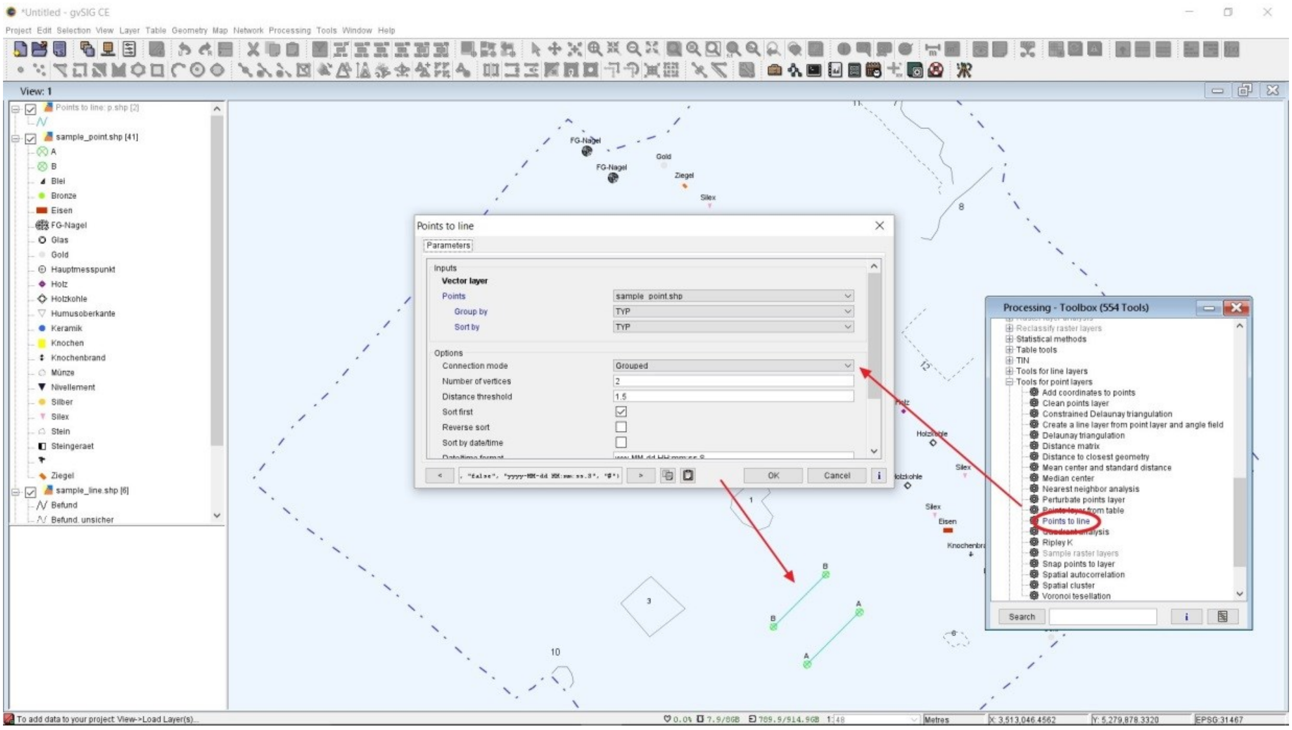


*Fig. 3. Automatic section line creation*

For the moment, development funding continues to be sustained by the Landesamt für Denkmalpflege. This, however, will not be feasible indefinitely. Possibilities for continuing development funding might be a collaborative platform on the Internet, paid-for support, and subscription models, actively advertised at specialist meetings and conventions. One of the most intriguing aspects of the Survey2GIS project is its ability to show how FOSS can unlock innovation potential. Prior to the inception of Survey2GIS, the Landesamt für Denkmalpflege’s field workflows had orientated themselves along the lines defined by user interfaces and functionalities of proprietary software, such as various proprietary CAD-systems. With the freedom to create new, customised software, however, also came the freedom to reassess and modify existing workflows in order to make them more efficient. The objective of this technical presentation is to make Survey2GIS more widely known to the international community, show survey2GIS in action with special emphasis on the building of “one button solutions” for specific projects or systems and to (hopefully) gain partners for the continued development of Survey2GIS.

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# TachyGIS – An Idea to Survey Archaeological Excavations with Total Station and GIS

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***Keywords:*** *Excavation—Survey—Total station—GIS*

**CHNT Reference:** Goeldner, Reiner. 2021. TachyGIS – An Idea to survey Archaeological Excavations with Total Station and GIS. Börner, Wolfgang; Kral-Börner, Christina, and Rohland, Hendrik (eds.), Monumental Computations: Digital Archaeology of Large Urban and Underground Infrastructures. Proceedings of the 24th International Conference on Cultural Heritage and New Technologies, held in Vienna, Austria, November 2019. Heidelberg: Propylaeum.
doi: 10.11588/propylaeum.747.

TachyGIS is an idea to survey archaeological excavations with total station and GIS. Former CAD based approach (with field book and 3D visualization) are transferred to GIS. The idea meets current challenges of total station survey like increased license costs, deficient attribute integration and insufficient sustainability (suitability to be archived).

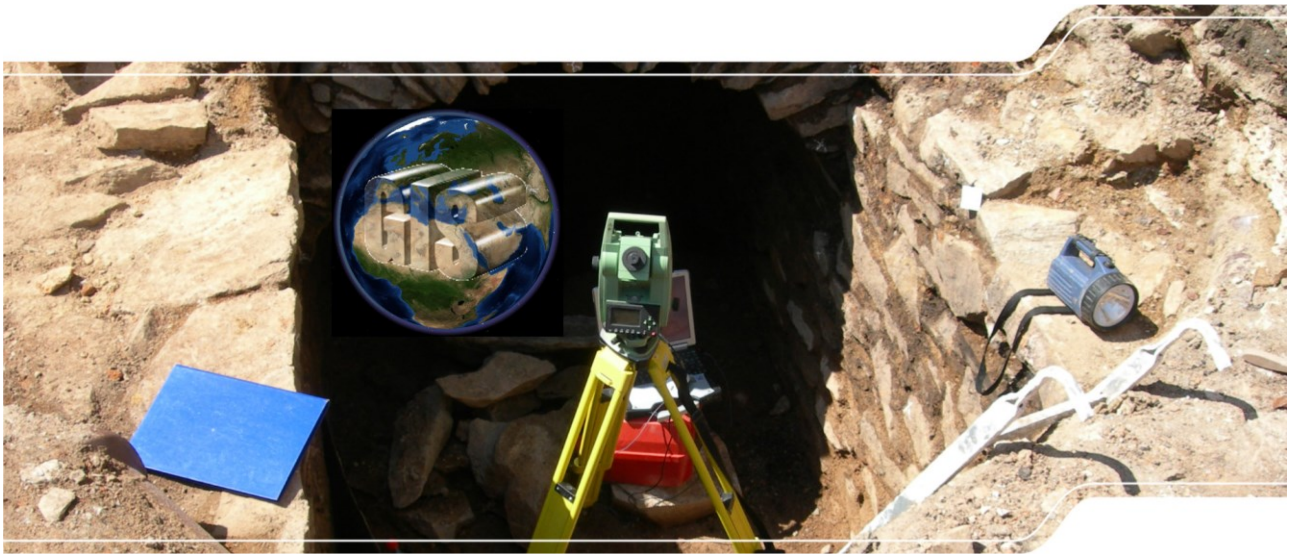

*Fig. 1. TachyGIS Teaser.(© Goeldner)*

The presented project idea “TachyGIS” is to transfer features of existing CAD based approach (especially coordinate transfer from total station and 3D visualization) into GIS to meet the above-mentioned challenges. Therefore, cost reduction is possible with cooperative FOSS (Free and Open Source Software) development, attribution is realized by GIS respectively geodata and sustainability can be achieved by using geodatabases with standard data formats. Valuable assistance comes from the “survey2gis” project (Survey-Tools, 2019).

FOSS has high potential to limit costs, not only by (cost) free use of existing software, but also by free development of user specific software components. There are only costs for new, additional software components. This positive effect can be multiplied by controlled cooperation! Using modularity and standardization lead to successful IT processes because they ensure flexibility and sustainability. Interacting with suitable cooperation they build a “Triangle of Success in FOSS” (Fig. 2), which is able to permanently reduce costs. Some more information on FOSS in German state archaeology can be find at VLA2 (2018).

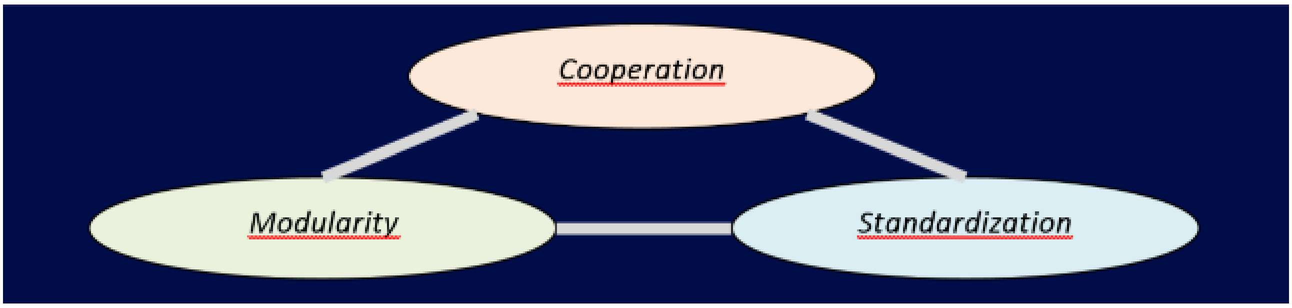


*Fig. 2. Triangle of Success in FOSS.*

The presented basic concept contains a system overview, a functional model and a data model (Göldner, 2018). A TachyGIS system contains of total station and field book / notebook with data connection. TachyGIS software modules import 3D surveying coordinates via total station interface and interact with appropriate GIS components to record and visualize them. Surveying data is recorded in a geodatabase in standardized and sustainable geodata format, so it is easily accessible from GIS and can be analyzed using GIS methods.

TachyGIS consists of three necessary functional components: total station interface, recording/attribution and visualization. Total station interface directly imports measurement data from total station to TachyGIS modules. Recording/attribution performs editing of geo objects (points, lines, polygons) from measured coordinates and assigns attributes like object ID or object type from controlled vocabulary. 3D visualization supports survey and recording. Besides that, many more functions to support daily excavation life are desired and an appropriate user interface is needed. But there are already many useful functions available in GIS that can be instantly used.

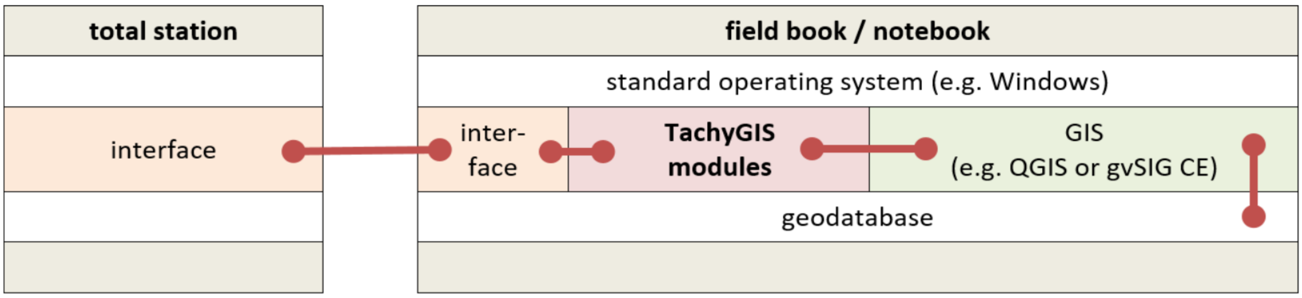


*Fig. 3. Basic TachyGIS structure.*

The Geodata model considers 3D recording of points, lines and polygons (areas). OGC standard “Simple Features Access” with WKT characteristic is recommended. Important attributes are: activity (excavation) code, basic object type, object ID (e.g. find no.), kind of object, annotation and remark. Further attributes and relationships are usually recorded in a specific excavation database and they may be linked by the object ID.

Sustainability of excavation geodata depends on realistic preservation strategies (that differentiate “archiving” from only “storing” the data). As showed in VLA (2017) and discussed in Göldner and

Bibby (2018), excavation geodata doesn't match the usual but simple format-based preservation approach, because they contain functionality. But it contains highly systematic information that can be handled with a customized database preservation strategy as mentioned in VLA1 (2018). If all geodata structures (of the database) are clearly standardized and documented and if there are alternative visual representations of maps and tables in PDF/A or TIFF format, an optimistic prognosis about a permanent preservation is possible.

Realization of TachyGIS is on the way. There is a prototype available that shows basic function of TachyGIS. The Hamburg Archaeological Museum maintained the development of all basic components of the so called Tachy2GIS software (Tachy2GIS, 2019). The first prototype worked fine, so it was interesting to test it over several months on excavations at the opencast mines near Weißwasser (Saxony). During these tests, the team improved the excavation specific geodata structure and developed a specific user interface for an optimized support of excavation workflows. The focus was on easy data acquisition in the field without extensive knowledge of QGIS-functions.

There are also further development activities, provided and coordinated by at least two institutions and foremost targeting appropriate 3D visualization followed by an excavation specific user interface and a more sophisticated interaction with the total station (e.g. to read and set prism height and to generate a more detailed measurement log file which then should contain stationing parameters as well as $r\vartheta\phi$ polar coordinates and prism height for every single measured point to enable effective debugging). And there is an expanding group of interested people in discussion about more detailed requirements.

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# First Experiences Using TachyGIS in Excavation Practice

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***Keywords:*** *excavation—survey—total station—GIS*

**CHNT Reference:** Schubert, Christof and Goeldner, Reiner. 2021. First Experiences Using TachyGIS in Excavation Practice. Börner, Wolfgang; Kral-Börner, Christina, and Rohland, Hendrik (eds.), Monumental Computations: Digital Archaeology of Large Urban and Underground Infrastructures. Proceedings of the 24th International Conference on Cultural Heritage and New Technologies, held in Vienna, Austria, November 2019. Heidelberg: Propylaeum.
doi: 10.11588/propylaeum.747.

The importance of GIS in archaeology has been constantly growing over the last years, not only for analysis and interpretation, but also for on-site documentation. In cooperation with the Archaeological Museum Hamburg, Tachy2GIS has been developed as a QGIS plugin to allow "live" measurements with Leica total stations in QGIS. A prototype of this plugin has been tested over several months on excavations at the opencast mines near Weißwasser (Saxony). During these tests, the team improved the excavation specific geodata structure and developed a specific user interface for an optimized support of excavation workflows.

*Fig. 1. Workshop Teaser "Digitale Grabungsdokumentation – objektiv und nachhaltig" (© R. Göldner).*

In general, the Tachy2GIS software (Tachy2GIS, 2019, Trapp, 2019) is closely connected with the TachyGIS Idea (Göldner, 2018) that summarizes the aspects of excavation survey with total station and GIS on an abstract level. This Idea was discussed at the Workshop "Digitale Grabungsdokumentation – objektiv und nachhaltig" (VLA, 2018). The Hamburg Archaeological Museum maintains the development of all basic components of Tachy2GIS. The existing prototype now is consolidated and extended due to basic requirements.

First, Tachy2GIS was a prototype without a practice oriented user interface. So, after knowing that the prototype works fine, we were highly interested to build a user interface that meets the needs of an archaeological excavation ("T2G_Archaeology" plugin). The focus was on easy data acquisition in the field without extensive knowledge of QGIS-functions. Here are some very short operating instructions, just to get a small impression:

- perform local stationing of total station
- click T2G button and open Tachy2GIS interface
- select COM port (connection to total station) and GIS layer (to save measurements)
- n* perform total station measurement, measured geometry is visible as (editable!) preview

- click OK to transfer object measurements into GIS layer (possibly use point snapping)
- attribute table of the object opens automatically and can be filled (there are drop down lists available that can be controlled by user defined CSV files representing customized thesauri)
- finally, the new geometry is displayed (don't forget to save)

The geodata structure handles 3D-points, 3D lines and 3D polygons separately (shapefiles). As the plugin will be used on a great variety of excavations ranging from prehistoric to medieval and from small one day investigations to large projects over several months to years, the layer attributes are reduced to a minimum. Our focus is on documenting the geometry of archaeological features. The most important attributes are:

- object_id (unique identifier),
- activity_code (excavation code),
- object_type (rough category: feature, find, sample, profile, …),
- object_species (detailed category: features: pit posthole, mural structure, …; finds: sherd, coin)
- annotation (for map layout purposes),
- remark (for all purposes).

So far, we believe these to be sufficient for fieldwork and basic map/report. External databases like those of specific research projects can be joined with the data to allow further analysis.

The used thesauri can be managed and edited from the user interface (ensure that all values are UTF-8). To speed up the filling of the attribute table an auto-attribute-function was introduced. This function automatically inserts several attribute values (like automatic numbering, object categorization) based on default settings that can be customized by the user (before a measurement).

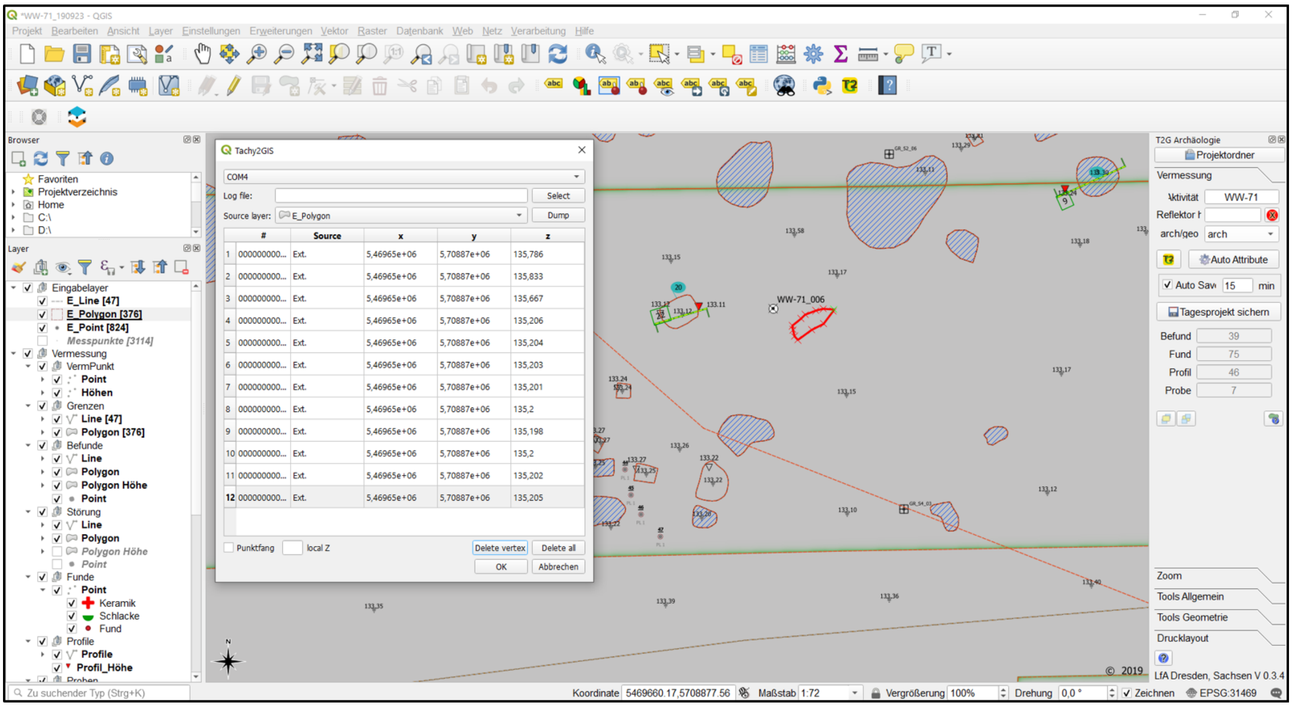


*Fig. 2. QGIS desktop with both Tachy2GIS and T2G_Archaeology plugin. (© C. Schubert)*

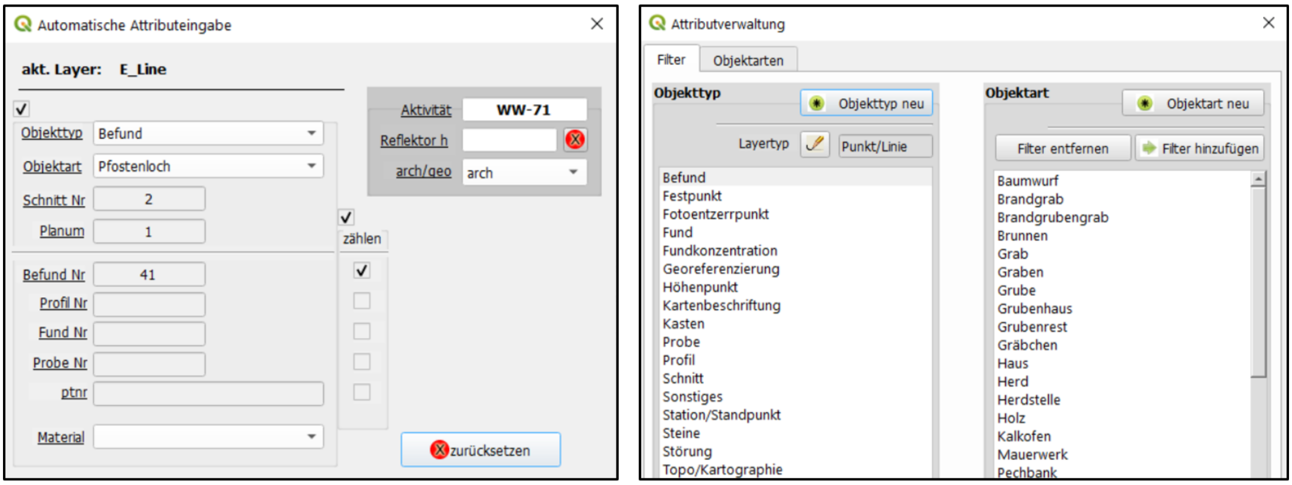


*Fig. 3. T2G_Archaeology plugin windows: automatic attribution (left) and attribute values (right). (© C. Schubert)*

It is also possible to easily import and export coordinate-lists, e.g., to transfer survey points for stationing to the total station or to import data measured with a GPS.

Some other functions would be fine, so further developing steps are planned. A clear and comfortable 3D visualization of the measured scene is needed for complex (inner city/medieval) excavations. An enhanced total station interface with bidirectional communications using Leicas GeoCOM is requested. This will allow e.g., to read and set prism height and to generate a more detailed measurement log file which then should contain stationing parameters as well as rϑϕ polar coordinates and prism height for every single measured point to enable effective debugging. Quite often, a local coordinate system has to be established before national coordinates are available for a site, so a user-friendly tool to transform measurements from a local into a national grid is also desired.

The résumé of using TachyGIS in excavation practice is: It works fine most of the time. It meets most needs of excavation projects that don't require very good 3D visualization. It allows the use of elaborated GIS tools to evaluate the excavations. And, because it's FOSS, it avoids the use of expensive CAD software. Further, expanded tests on our excavations will allow me to identify bugs and optimize our data structure while an ongoing software development will meet the above mentioned requirements.

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# Poster Session

## Short Papers on the Poster Presentations of the Conference

# Air pollution impact on Mediterranean architectural heritage

## Molecular analysis of black crusts deposits

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***Keywords:*** *Air pollution impact—Mediterranean monuments—Black crusts analyses—IR and synchronous fluorescence spectroscopies*

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doi: 10.11588/propylaeum.747.

## Introduction

The present investigation relates to air pollution impacts on architectural heritage; it is the continuation of the previous published works (Lamhasni, 2019 and Ozga, 2013). Black crusts deposits on four historical monuments at the Mediterranean region (Fig. 1) were analysed by means of optical spectrometries. At the southern side, the investigation related to the “Burg Al-Klab” tower in the city of Salé and the Mosque Al-Qods of the Roches Noires neighborhood in Casablanca. These limestone buildings, dating back respectively to the late of the 12th and the beginning of 20th centuries, are highly exposed to road traffics and are suffering from air pollution. At the northern side, the monuments considered are: i) the cathedral of Milan, dating back to the XIV–XIXth centuries, which is one of the most attractive edifices of Milan and ii) the Santa Maria Del Fiore Cathedral of Florence, edified since the XIIIth century, part of the most important monumental complexes in Italy. For the first time, the molecular/structural techniques of Synchronous fluorescence and ATR-FTIR spectroscopies were combined for the analysis of hazardous polycyclic aromatic hydrocarbons (PAHs) along

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with calcite degradation products in black crusts sampled on the exposed façades of the above Mediterranean monuments.

As in European areas, in the case of Morocco, the cities of Casablanca and Rabat–Salé are also subject to the problem of architectural heritage disfigurement; there are numerous buildings, dating back to different historical periods, suffering from air pollution. The expansion of industrial and urban areas is drastically increasing the atmospheric pollution and its harmful impacts on all environmental compartments.

Gaseous pollutants, suspended particulates matter (PM) and aerosols released from combustion processes are accelerating the deterioration of historical buildings in urban areas. Particulate matter (PM) and sulfur dioxide (SO2), in dry and wet depositions, are the most aggressive and dangerous agents for architectural heritage. In the case of limestone (the worldwide used ancient building material) as well as marbles, soiling, color changes and black crusts depositions followed by material loss are the most common observed alterations. Exposed to severe weather, limestone, which is a naturally porous material, behaves as a non-selective depository, passively entrapping airborne particulate matter, gaseous organics and carbonaceous particles. In particular, the entrapped carbonaceous particles act as catalysts in the calcite sulphation process and induce the blackening. They play thus the important role in the overall deterioration affecting the exposed façades of ancient buildings.

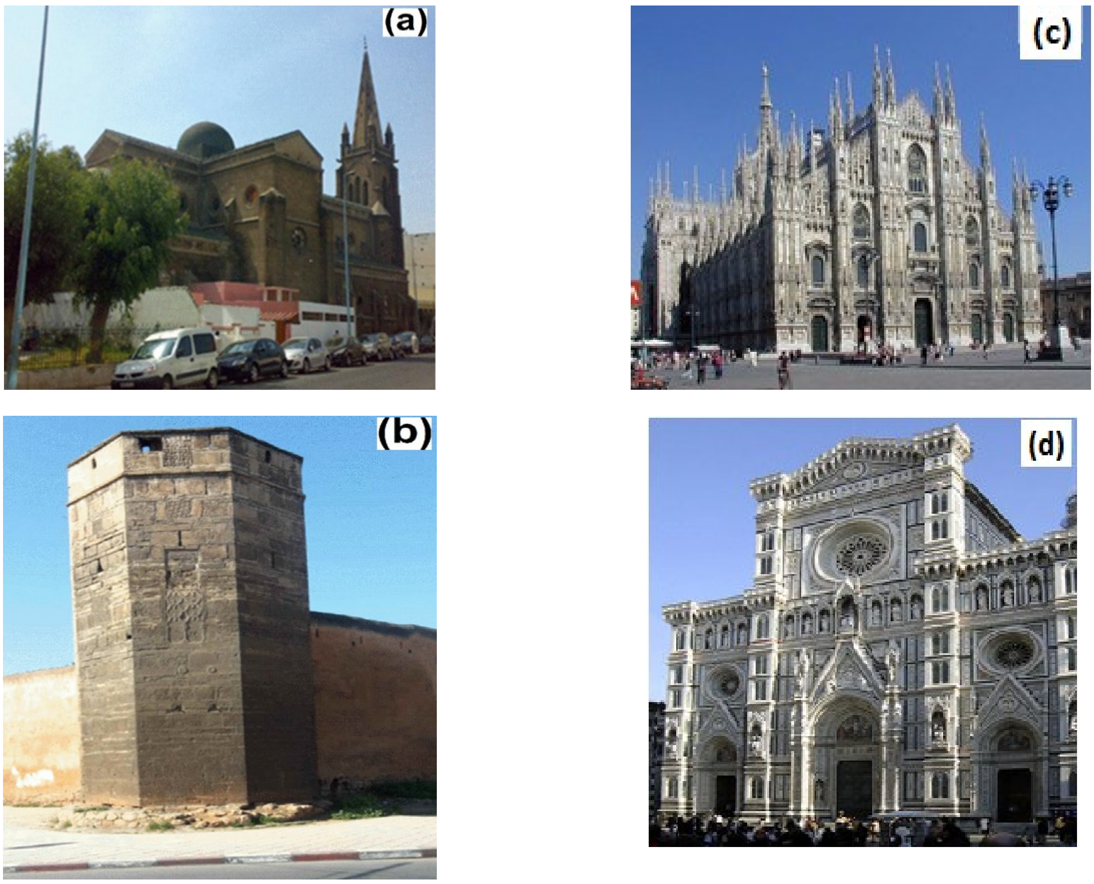


*Fig. 1. Mediterranean buildings: Moroccan buildings: a) Al-Qods Mosque (Wikipedia) and b) Burg Al-Klab tower (© Authors). Italian buildings: c) Cathedral of Milan d) Cathedral of Florence (Wikipedia).*

## Results and discussion

In the present case black crusts deposits collected on the monuments façades were studied by means of combining constant-wavelength synchronous optical fluorescence and ATR-FTIR spectroscopies. Fig. 2 and Fig. 3 show respectively the synchronous fluorescence spectra (SFS) of black crusts dissolved in acetonitile, and the ATR-FTIR spectra recorded directly on black crusts particles. All SFS were recorded at the same offset 10 nm value. In all cases, the comparison of the obtained synchronous fluorescence spectra (Fig. 2) with those formerly established for hazardous PAHs (Lamhasni, 2019) permitted the identification of eight PAH groups: i) Fluorene ii) Acenaphthene, iii) Phenanthrene, iv) Chrysene and Pyrene, v) Anthracene, Naphthalene, Benzo (b) Fluoranthene, Dibenzo (a,h) Anthracene, Benzo (a) Anthracene, Benzo(k) Fluoranthene and Benzo (a) Pyrene, vi) Perylene, vii) Indeno (1, 2, 3, cd) Pyrene and viii) Fluoranthene. These PAHs groups are emitting respectively in the wavelength ranges 290–315 nm, 315–335 nm, 340–355 nm, 355–375 nm, 375–415 nm, 430–450 nm, 455–475 nm and 475–490 nm. The red sides, 500–600 nm, observed in all fluorescence spectra may be related to hydrocarbons with aromaticity degrees higher than those of the identified PAHs, crude oil from Iraq had been reported exhibiting fluorescence features in the same spectral range (Naseer, 2016).

The ATR-FTIR spectra recorded on black particles did not show similar infrared spectra for all edifices (Fig. 3). While the spectra recorded on black crusts sampled on the Moroccan limestone buildings show bands characteristic of both of gypsum and oxalates degradation products, the spectra recorded on black crusts collected on the Italian marble buildings exhibit only bands characteristic of gypsum. The gypsum (CaSO4.2H2O) signals are those located at 600, 672, 1109, 1684, 3397 and 3533 cm-1; the oxalates (whewellite CaC2O4.H2O and weddellite CaC2O4.2H2O) ones are observed at 1618 and 1321 cm-1 along with the large spectral block lying between 2900 and 3700 cm-1. Gypsum originates from calcite sulphation under wetness and SO2 rich oil fired soot, while oxalates are due to ancient biological weathering. The presence of oxalates in the case of the limestone buildings, against their absence in the case of the marble ones, indicates clearly that the porosity of the lime stone material may constitute a factor of its vulnerability compared to the marble one.

## Conclusion

Considering the remoteness of the four historical buildings, as well as the great difference between the northern and the southern Mediterranean climates, the similarity between the identified hazardous organic pollutants along with the degradation product gypsum, indicates that the weathering factors impacting negatively the building materials are of the same origin. These factors causing disfigurement of historical edifices are obviously carbonaceous particles originating from fossil fuel and oil combustion due to traffics expanding over decades.

Such results keeping track of air pollution, inducing degradation of architectural heritage, must alarm both cultural heritage and environmental decision makers.

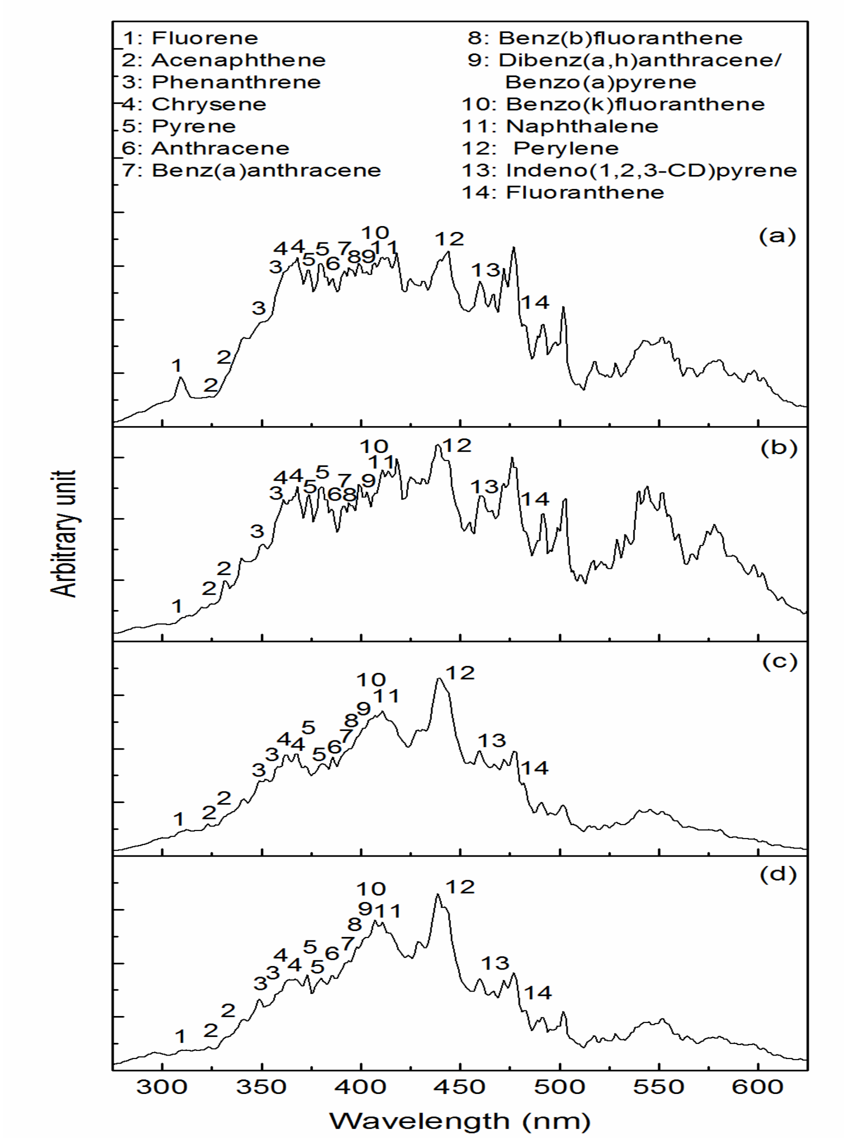


*Fig. 2. Synchronous fluorescence spectra of black crusts extracts in acetonitrile, recorded at the offset Δλ = 10 nm. a) Mosque Al-Qos in Casablanca, b) Burg Al-Klab in Sale, c) Cathedral of Florence and d) Cathedral of Milan. (© Authors)*

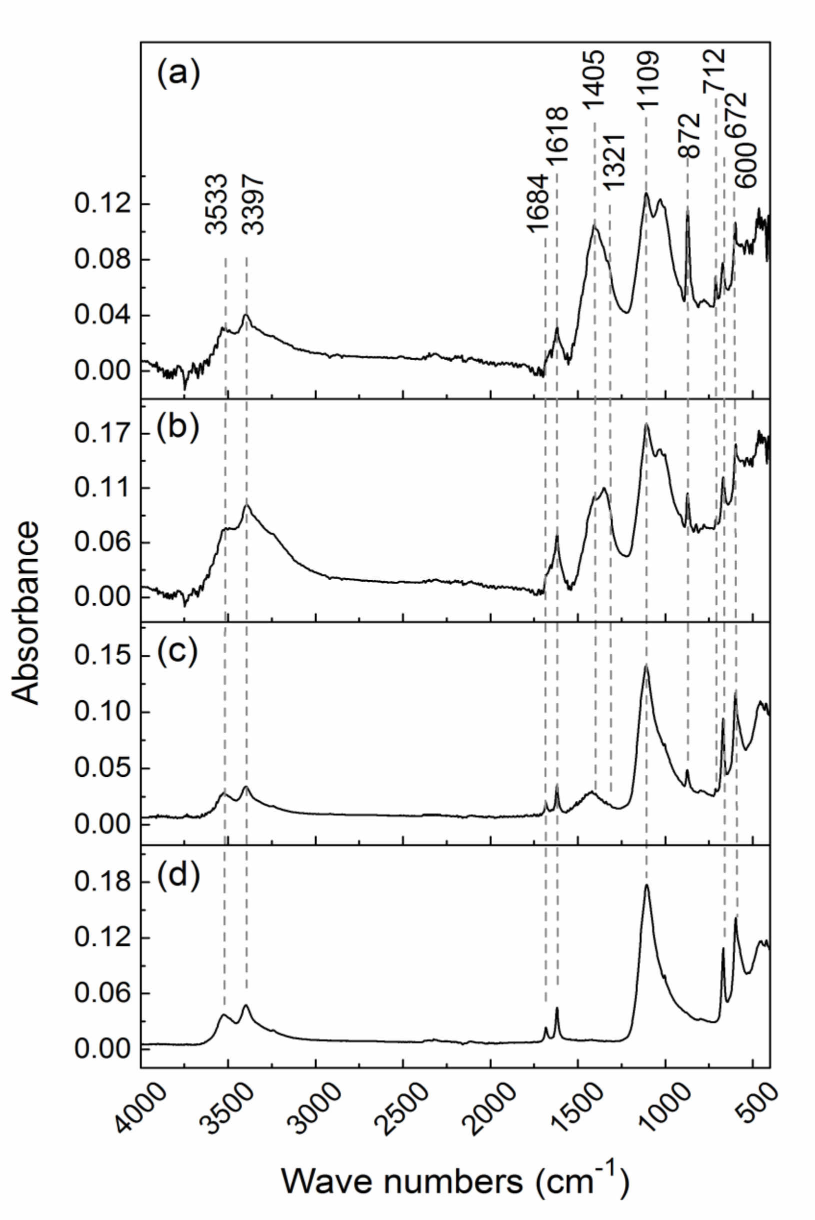


*Fig. 3. ATR-FT infrared spectra of black crusts particles sampled on the facades of a) Mosque Al-Qos in Casablanca, b) Burg Al-Klab in Sale, c) Cathedral of Florence and d) Cathedral of Milan (© Authors).*

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# From un-real to real and return

## Some example of activities of a modern model's lab

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***Keywords:*** *Architectural Model—3D Print—Representation—Model-Making*

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## Abstract

The Architectural Models Laboratory (LMA) has completed its first 6 years since its foundation. Perfectly integrated into the DIDALABS system of the Dipartimento di Architettura, University of Florence, Italy, it offers support for student's exams and bachelor/master thesis graduation, PhD research as well as thematic seminars and workshops, coordinated by researchers or professors of Florentine Athenaeum. During these moments, students together with the technical and research staff of the laboratories realize physical models and study prototypes (Moon, 2005).

The Architectural Models Laboratory also collaborates with other universities, departments, and external organizations such as museums or architectural firms, to offer them a specific set of competencies and digital/physical tools (Gavinelli, 1993).

The Laboratory offers different technologies both traditional and modern (Mi-young, 2012). From woodworking to 3D printing, from 3D scanning to laser-cutting (Ratzlaff, 2016), with the consultancies of the laboratory team, it is possible to build and/or refine ideas (cp. Knoll, 2007; Ansgar, 2011). In this poster, a selection of experiences presents the main occasions and solutions connected to Architecture, Archaeology, Cultural Heritage, with a special focus on those planned and defined in recent years. The selected works will be presented in the will of sharing the procedures and results of each specific case study.

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## Vieux Port and Hotel Gourara

The traveling exhibition “FERNAND POUILLON opere scelte 1948–1968 COSTRUZIONE CITTÀ PAESAGGIO” (Selected Masterpieces from FP, 1948–1968, BUILDING, CITY, LANDSCAPE) curated by Giulio Barazzetta from the Dipartimento di Architettura, Ingegneria delle costruzioni e Ambiente costruito (DABC) Milan Polytechnic, Renato Capozzi from Dipartimento di Architettura (DiARC) University of Naples “Federico II”, Catherine Sayen president of the Association “Les Pierres sauvages de Belcastel” Toulouse and  Prof. Francesco Valerio Collotti From Dipartimento di Architettura (DIDA), University of Florence, was an opportunity to contribute to the dissemination of the results of a research on the work of Fernand Pouillon.

The architectural models of Vieux Port in Marseille and of the Gourara hotel in Timimoun were the contribution that the Laboratory gave to the exhibition, and together with others, were exhibited in Florence, Rome, Milan, Venice, Cesena and later in Lausanne, Marseille, Lyon and Paris.

Both architectural models, in scale 1:200, were made using wood and white and opal polymethylmethacrylate plates, cut with a $CO_2$-based laser system.

*Fig. 1. Model of the Vieux Port in Marseille, detail (© Authors).*

## A new face for the new Novoli thermal power station

During the thematic seminar “Un nuovo volto per l’ex centrale termica Fiat” (A new face for the former FIAT energy facility in Florence) organized by Prof. Antonio Capestro and Prof. Leonardo Zaffi and with the collaboration of the artist Clet Abraham, two models were created. One in wood, 1:25 scale, representing the “Ex-centrale termica FIAT” in Florence, a backdrop on which the artist would have placed his work. The second model represented the artist’s work and was created starting from paper sketches made by Clet himself, subsequently scanned with a Microscribe 3-D G digitizer coupled with a Skiron laser scanner head. This process led to the final definition of a virtual model of the work that can be used for its prototyping with both additive and subtractive technologies.

## Marina Abramović - The Cleaner

In April 2018, the Palazzo Strozzi foundation – after a direct request of the artist Marina Abramović—it was commissioned to the LMA an architectural model representing the First Floor and the basement of the Florentine Palace from which the foundation takes its name. The required scale—1:50—led to the creation of two models of about three square meters each.

Marina Abramović worked on the model for designing the exhibition "Marina Abramović – The Cleaner" opened in September 2018 (Abramović, 2018).

## Medusa's heads from the Istanbul Cistern

These models are a typical example of what the collaboration of students and researchers can produce in the model laboratory. Starting from the digital modelling of a photogrammetry work, a procedure to represent the geometries and the ideas through the exchange with the laboratory technicians, the technologies and the interests of the students/researchers have brought in most of the positive results. In this case, it is a model of Istanbul Medusa's heads, printed with colour binder jetting technology, producing a scaled model extremely useful to understand this specific spolia and bring them back to their original story. From a personal research project curated by prof. Giorgio Verdiani, in collaboration with dott. Andrea Pasquali and dott. Ylenia Ricci.

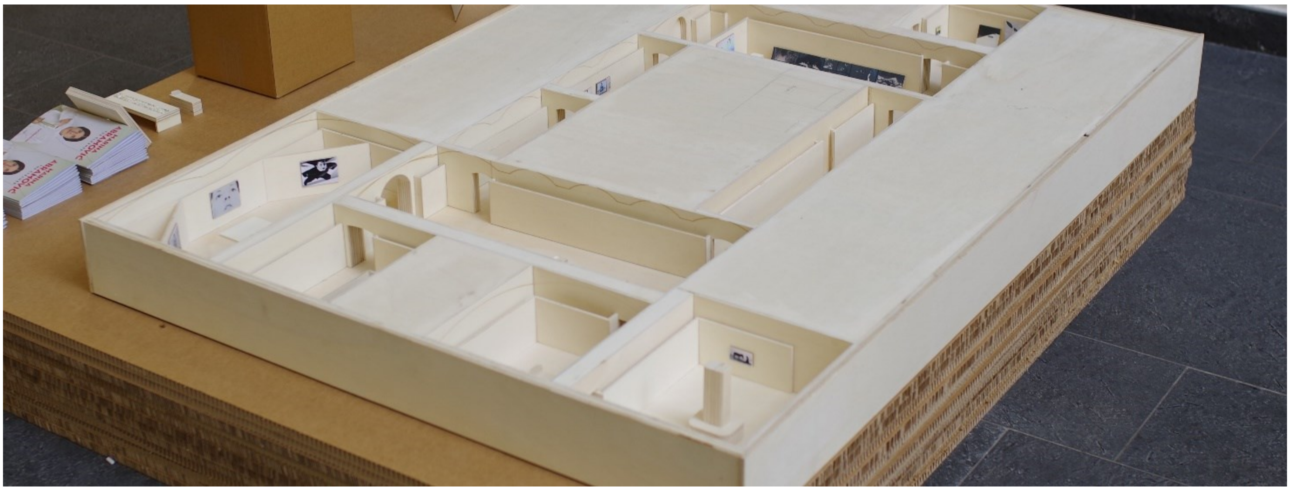

*Fig. 2. Model of the basement of Palazzo Strozzi in Florence (© Authors).*

## Ando's Ito House Series

These four small models of Ito House by the architect Tadao Ando are just a few pieces of a wider collection of models in production at LMA. One of the aims of this project is to examine the expressiveness of different materials and techniques in a physical architectural model: maintaining the same scale how is the models' ability to communicate going to change? How will the chosen material influence this ability? Through the realization of these models, we can study how the matter information influences the perception of a scaled architecture. The project, Casa Ito, has been selected because it contains point-like elements, as well as curved and thin ones, elements that usually generate difficulties in the realization of a scale model. The reproduction scale has been set at 1:300 for all models, to have compact volumes, to investigate the management of small-scale detail and at the same time guarantee variety of materials.

## The Earlier Mona Lisa

The laboratory has worked to expand the accessibility of cultural heritage by creating tactile models of works of art such as the Earlier Mona Lisa by Leonardo Da Vinci. Starting from the geometric data of the paint, the tactile aspects of the work were analysed. The geometries were modelled in using Pixologic Zbrush and then 3D printed. Finally, the laboratory prepared the geometries of the painting of the famous Louvre Mona Lisa, to be used for comparison purpose. Some Details of the territory and from the figure in the masterpieces were printed to complete a full “learning by touch” desk integrated into the “Earlier Mona Lisa” exhibition (which opened in Florence during June–July 2019, Beijing 2020). Responsible for research: Prof. Giorgio Verdiani.

*Fig. 3. Mona Lisa’s physical model (© Authors).*

## Research Project in Jerusalem

The request from Prof. Fabio Fabbrizzi was the construction of four solid wooden models. The idea was to create expressive models using a single wood kind, for all the volumes, and satin Plexiglas for some small details. The chosen scale was 1:250 to allow legibility of the project through his inclusion in the urban context, his richness through the right balance of details and the enhancement of the wood characteristics. The adjustments made concerning the original model have had the purpose of maintaining the maximum possible detail allowed by the workability of the material and the timing of its realization.

## Wind gallery

Different models for the wind tunnel have been made with the CRIACIV laboratory of the Dipartimento di Ingegneria Civile e Ambientale (Civil and Environmental Engineering Department, University of Florence). These functional models take a different approach than the architectural representative models. Using the technologies present in the laboratory and the expertise of the staff, it was possible to satisfy the demands of the CRIACIV and to realize some sample models of the new terminal of the airport of Rabat.

This series of examples, presented in form of summary in the poster and then expanded in the following paper will show different approaches to design, cultural heritage, archaeology and artworks from the architect's point of view. The balance between the tactile experience to the materialization of the ideas will be examined in two parallel paths: the use of the model as an element of the exhibition (for attraction or learning purposes) and the use of the model as an element of visualization/understanding of the effect of the design process. In this, the list of proposed samples will be not in order or aligned to an "evolution" but presented in a mix of different questions where the skill to find a solution pass by the production of a physical model using both traditional and/or digital procedures of production.

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# Robust radio link solution for a semi-autonomous underwater vehicle

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***Keywords:*** *semi-autonomous underwater vehicle—intelligent buoy—sonar—Keutschacher See*

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## Motivation and Introduction

Since GPS is not easily received in water, localisation in the sub-documentation still poses a major challenge (Baletti, 2015). Furthermore, the working time of a research diver is limited and requires special safety precautions (Papadimitriou et. al., 2015).

The use of low-cost mini submarines is a candidate to meet both challenges. On the one hand, no decompression breaks are required and on the other hand, available systems can penetrate to a diving depth of 100 meters and deeper. In combination with self-localization algorithms, which enable live 3D reconstruction and are used in autonomous robotics, orientation and localization tasks can also be solved with a good view of the subsurface. Since the transmission of signals under water is not possible, all currently available mini-submarine systems transmit the control and video signals via cable. This cable can have a length of several hundred meters. For practical documentation work, e. g. in shallow water areas, special cable management solutions are required (Block et. al., 2018).

*Fig. 1. The diving robot "Manio" documents semi-autonomously a pile dwelling settlement. Since the system has not yet reached market maturity, it is supported by a snorkeler who can intervene if necessary.*

This poster presents a robust wireless solution that can reliably transmit both control and video signals. A radio buoy was developed for the BlueROV 2, which has already been used successfully in various documentation campaigns. The buoy was extended by a sonar and will serve as a further sensor for localization in the future. At Lake Keutschacher See in Austria, the system was successfully used with a radio range of up to 500 metres (see Fig. 1).

## Construction and realisation of the radio link

There is a base station on the shore. Here the control and video signals are controlled and monitored. A directional antenna from NanoBeam with 5 GHz at the base station is used to realize the radio link to the buoy. Inside the buoy two omnidirectional antennas receive the radio signals. In order to enable a parallel propagation of the radio waves over the water surface, the antennas were installed orthogonal to the water surface.

The buoy can receive radio signals from any direction with the presented solution. The system enables a transmission speed of approx. 640 MBit/s and has a latency of 1.3 ms on average. Thus the signals are transmitted in real time. The documentation campaign at Lake Keutschach has shown that the system works reliably at a distance of 500 metres.

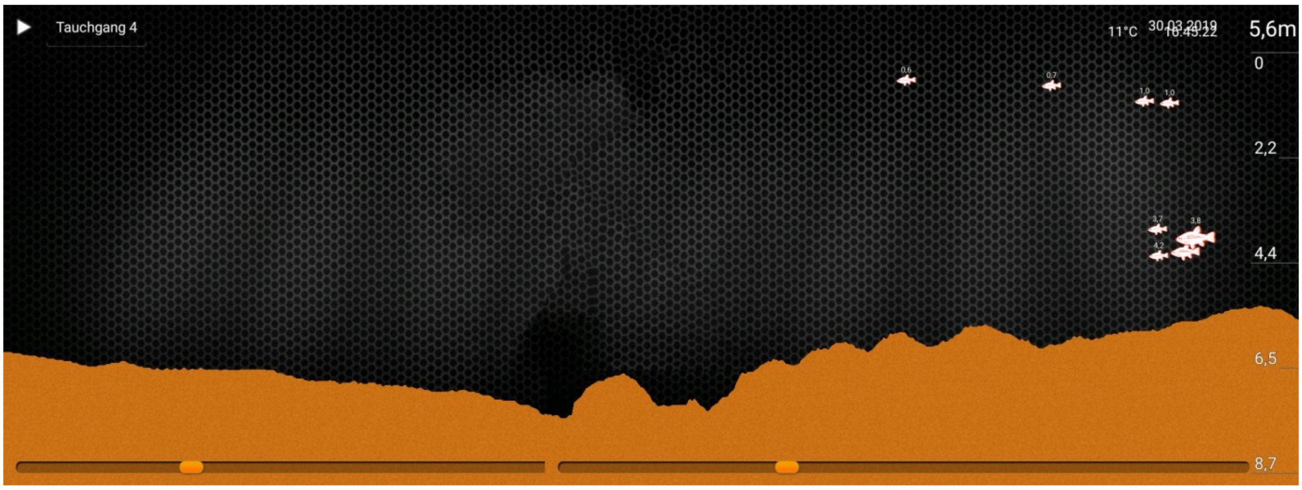


*Fig. 2. The buoy pulls the sonar sensor Deeper Pro Plus about 20 cm behind it. The available data is read out live and also transmitted via the radio link. You can see a time series during one of the dives at Lake Keutschacher See.*

The available bandwidth makes it possible to transmit different data in parallel. This includes sonar data (see Fig. 2), GPS positioning of the buoy and sonar, temperature data of the submarine and buoy, diving depth, speed and direction of the submarine, control signals and live video signals from various underwater cameras.

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# Torre degli Embrici: a sign of ancient cultures

## Digital survey of ruins of Torre degli Embrici in Rionero in Vulture, Italy

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***Keywords:*** *digital survey—ruins—3D—Roman archaeology—Roman thermal baths*

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doi: 10.11588/propylaeum.747.

### Abstract

This research originated from the curiosity to discover an abandoned area in the Melfi's part of Vulture territory, province of Potenza, in the south of Italy.  A team of archaeologists worked for digging activity from 2004 to 2009 but then, due to administrative reasons, the work was interrupted and the whole area was abandoned definitively.

In the location "*Torre degli Embrici"*, archaeologists executed a grid pattern of the area with mesh of 5 × 5 m and extensions of 120 × 60 m; the structures can be dated from the 2nd century to the 7th century A.C. The ancient part of the site is a Roman villa that includes thermal rooms with various extensions; unfortunately the height of the walls is cut under the level of the ground and it's hard to collocate with certainty the various rooms of the villa and thermae. It is known for sure that it was collocated close to an important road axis in the Roman viability, via Herculia. This road was connected with Via Appia and it's quite possible that in that period reached the city of Heracleia passing through "*Torre degli Embrici*". This road allowed crossing a wooded land whose viability was not yet well developed and this permitted the exchange of goods from population located to the south of Roman territory.

In this site, it's very interesting to study the different phases of the building of the villa and how it was developed in the different centuries.

The aim of the archaeological investigation was first to give an organic view of the steps of the process of anthropization of the area. The archaeological evidences of rural settlements with villas at the end of the 3rd-2nd century B.C. are not always clear and are open to different interpretations that can change the proposed dating. Most of the times these settlements have a long continuity of life and were often subject to activities of restructuring and extension between the late republican

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and imperial age which makes it very difficult to discover the true extent of the construction interventions in the building establishment phase.

The site of "Torre degli Embrici" has pre-Roman origins connected to the settlement of Lucani population. Many sites where this population settled in the Melfi's part of Vulture where utilized in Roman period. Thanks to the numismatic discovery in the hypocaust part of the thermal rooms and thanks to the analysis of the tiles discovered, the first building phase can be dated around the 2nd or the 1st century B.C.; the finding of an emperor Probus coin confirmed that the first building of the site was around 2nd century B.C. Later the balneum was extended and also a second thermal area with *calidarium* and *tepidarium* was built without breaking down the existing parts. A new reconstruction phase, in the 4$^{th}$ Century A.C., led to levelling of existing structures and the new ones were built above. A large apse of 11 meters ca. was added to the previous structures.

Thanks to the discovery of some ceramic remains founded under the floor and of some plaster removed directly from the apse, it can be dated around the end of the 5$^{th}$ century A.C. Some other findings are dated around the 7$^{th}$ century A.C.

The purpose of the relief was bringing to light the whole area in order to raise awareness, among the community and the public administration, to protect and enhance this heritage.

The work started with an inspection where we decided to proceed with an indirect relief executed with a drone (Inspire 1 pro) which flew over the entire site taking pictures.

The photos (Fig. 1) were taken following the orientation of the dig, both longitudinally and transversely, using the photogrammetry rule, which intends to keep in the new picture 1/3 of the points in common to the previous one.

Then the pictures were imported to the software "Reality Capture" to get a first model through different steps. The first step was to align the photos in order to create a point cloud; this will be less detailed where images have too few information; this problem has been resolved with the reconstruction of the box of selection. The second step concerns the reconstruction of the point cloud in "normal Details" to create rendering/3D model. In this way, the model can be extremely faithful to reality. The third step involved the creation of the "texture" which means the analysis of the pictures used and then the application of these textures on the obtained model. (Fig. 2)

With this software it was possible to reconstruct the wireframe plan into AutoCAD, allowing also to obtain the altimetry of the structure, the dimensions of the "*domus*" rooms, the identification of the most damaged parts subjected to the changes of climate and environment. (Fig. 3)

## Figures

*Fig. 1. Photo of a part of the Roman site (© Authors).*

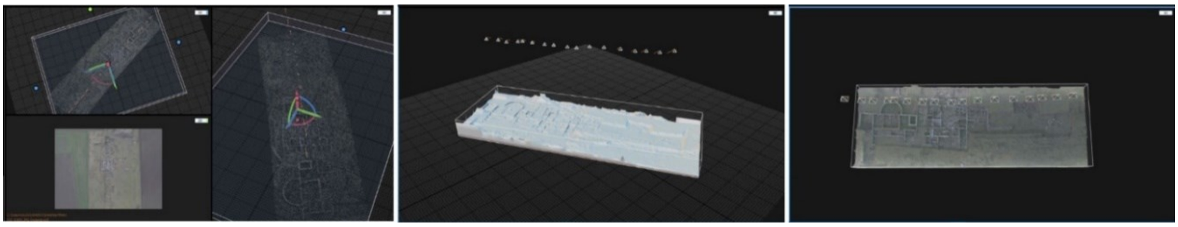

*Fig. 2. Transition from point cloud to a mesh textured model (© Authors).*

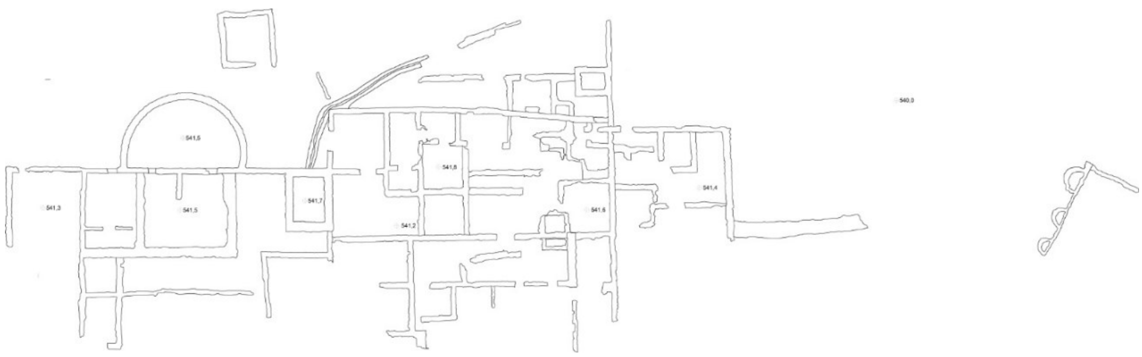

*Fig. 3. Digital survey generated with the software AutoCAD*

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# "Wrapping Ruins Around Buildings"[1]

## The Roman *Villa delle Grotte*

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***Keywords:*** *Roman Villa—Architecture—Archaeology—Elba Island—Architecture Design*

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### Imaginable absences

On the promontory overlooking the Gulf of Portoferraio, on the island of Elba, lie the remains of the Roman domus known as Villa delle Grotte, characteristic example of the luxurious *villae maritimae* of the Augustan era. The building, typically defined by the courtyard which its rooms had to look out, stands on a base supported by a series of apsidal structure, the *grotte*. This podium, still present today, is witness to the link between architecture and landscape.

### General issues

The Villa delle Grotte appeared on the list of monumental buildings for the first time in September of 1901 (Alderighi, 2014). In the report the remains of the building were described as follows:

"On the two sides of the road that leads from Portoferraio to Portolongone, on a hill that juts out towards the gulf of Portoferraio there are long stretches of walls of Roman construction *ad opus incertum* and *opus reticulatum*, of vaulted undergrounds, of sections of brick wall, remains of mosaic floors, and other traces of constructions, and marble coverings."[3].

Documentation prior to this date is almost non-existent. Only some views from the eighteenth century and a drawing in the Ciummei manuscript (1786–1791) show us how the Villa must have been before the destruction by the Neapolitans who installed the artillery on the ruins, during the siege of 1799 (Casaburo, 1997). Many of the current knowledge concerning the archaeological area comes from the excavation campaign conducted by Giorgio Monaco between 1960 and 1972, the documents drawn up at the end of the excavations are still one of most complete sources of information on the building. Giorgio Monaco's diaries and the drawings by R. Pasquinelli describe the state of the archaeological site at the end of the excavations. Interesting is the description of the search for the western boundary of the structures, in this part situated near the street where Giorgio Monaco chose

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[3] Translated from the copy of the document AST 9 Livorno 24 1953-1960- Soprintendenza ai Monumenti e Gallerie per le province di Pisa, Lucca, Livorno e Massa-Carrara, nell'elenco degli edifici monumentali.

not to proceed with the excavations, as if this area was not part of the complex. In this section, known as the *giardino delle essenze*, which was probably once shielded by an arcade (*ambulatio*) towards the South-West, he preferred to create an open space to park cars and tourist coaches (Alderighi, 2014). The situation today is unchanged, at the entrance of the villa, at the point where the visitor could embrace the immensity of the area and its direct relationship with the landscape, there is a parking lot and a small temporary structure for the reception.

During the course of Architectural design and composition of the bachelor's degree in construction engineering of the University of Florence[4], we asked ourselves how to re-establish the visual and physical link between man, memory and landscape, while maintaining at the same time the services necessary for managing archaeological excavations. Through the example of the villa, and based on the reconstructions made by Giorgio Monaco, small architectures have been hypothesized, capable of establishing relations with the ruins. These relationships are based on the themes of construction measurement, and variable landscape *warping*. The ancient construction is credited with having defined a rule of intervention for this place. Terraces, rooms of passage, fences and *hortus conclusus*, have become the main themes of the composition. Three project hypotheses designed on the basis of the same functional programme are shown below.

## Three Ways – Three Different Principles of Relationship

### THROUGH – by L. Galletti, N. Lucchesi, U. De Biase.

This project proposal tries to mend the connection between the ruins of the Valeri villa (Pancrazzi,1995 and Cambi and Pagliantini, 2014) and the landscape that surrounds it. This project defines a path that goes from the Giardino delle Essenze to the sea. The services directly connected to the archaeological area find place inside a small building, an inhabited wall, whose dimensions make it look like a simple wall, which screens the view of the ruins from the street and from the Giardino delle Essenze. Past this new threshold, there is access to the maze of rooms that made up the villa. The descent towards the sea begins through a tortuous path. Placed halfway through the descent, the recreation services and finally, precisely in that contained but deep inlet (perhaps the one painted by Lorenzo Ciummei), a small amphitheatre.

[4] Collaborators: Arch. Antonella Sedda, Arch. Marianella Stillavato, Arch. Bernardo Criscuoli, Ilaria Borghesi.

Participated Elsa Innocenti, Serena Galerati, Beatrice Cassini, Asia Garrisi, Francesca Rosafio, Astrid Panitti, Andrea Menci, Alessandro Baronti, Matteo Di Ruberto, Lorenzo Cassigoli, Francesco Contini, Francesco Maiorana, Francesco Meozzi, Leonardo Sanesi, Mattia Marchetti, Viola Neri, Viola Tilli, Niccolò Martinetti, Edoardo Cappelli, Mirco Cenni, Lorenzo Pampaloni, Alessandro Trenti, Filippo Pratesi, Gianmarco Falorni, Ayoub Harrat, Lorenzo Senesi, Chiara Fanelli, Filippo Capanni, Denise Frappi, Edilberto Mangani, Filippo Castriota, Giuseppe Latte, Alberina Bibaj, Ilenia Giannini, Sara Melis, Andrea Bonini, Alice Gori, Emanuela Pili, Aldion Shabani, Andrea Zeloni, Edoardo Solenni, Alessia Cresci, Niccolò Bonamici, Edoardo Peruzzi, Arlind Mersini, Andrea Nerini, Marco Longi, Emanuele Porta, Guglielmo Nasorri, Giulia Perugini, Arianna Mauro, Rocio Celestino, Mohamed El Hakimy, Nicolas Alarcon, Chaimaa Khalid, Anna Di Dio, Ilaria Muccio, Nicolò Lucchesi, Umberto De Biase, Lorenzo Galletti, Antonino Gringeri, Giulia Valentini, Chiara Paoli, Francesco Giovannini, Eleonora Roselli, Annalisa Pancani, Maroua Nouri, Gabriele Calabrò, Matteo Sbrolli, Elisa Iaconisi, Francesca Cataudella, Anas Hasbi, Mark Magligat, Koami Moise Agbenowossi, Lorenzo Ciatti, Medon Mustafaj, Sergio Fabian piedrahita Velez, Ilaria Crudo.


*Fig. 1. THROUGH reworking of the architectural project designed by L.Galletti, N.Lucchesi, U.De Biase.*

## OVERLAP – by M.El Hakimy, F.Giovannini, N.Alarcon.

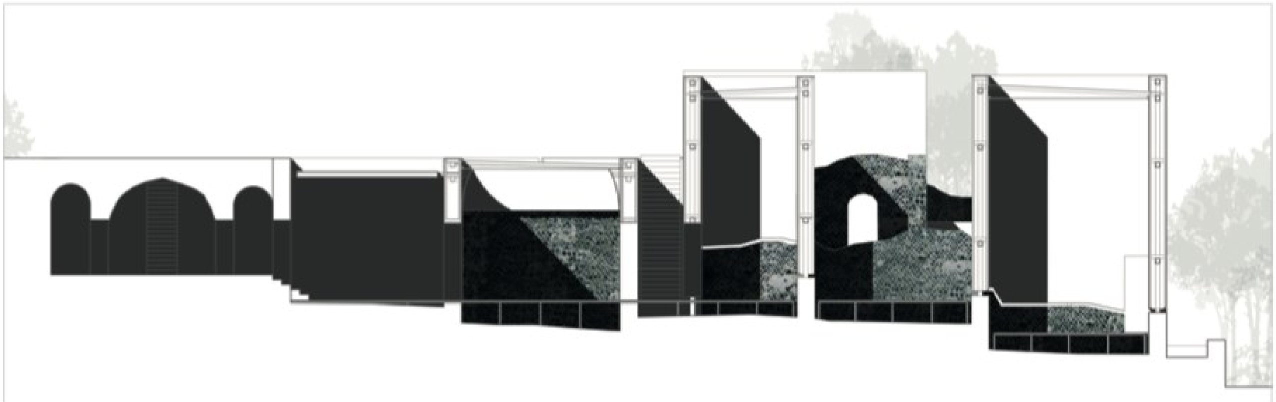

*Fig. 2. OVERLAP reworking of the architectural project designed by M.El Hakimy, F.Giovannini, N.Alarcon.*

This project proposal is developed on the western part of the Villa, among the remains of the thermal baths of the 1st century A.D. These rooms, only partially recovered from the excavations conducted by Giorgio Monaco in the 1960s, are the best-preserved part of the Villa. Based on Carrilho da Graça's idea for the archaeological site of Praça Nova, the project foresees a series of volumes which planimetrically trace part of the ruins and reconstitute the South-West corner of the Villa without any objective reconstruction.

## DISTANCE – by G.Perugini, A.Mauro, R.Celestino.

Upon arriving at the archaeological area, before seeing the remains of Villa delle Grotte, the eye is led to look toward the Gulf of Portoferraio, Cosmopoli and the sea. The necessary distance to observe the remains of the Roman Villa is missing, our gaze cannot completely embrace the immense archaeological area. From the upper Cistern, however, it is possible to truly understand the villa and its relationship with the surrounding landscape. The still existing building becomes the place where it is possible to know the ruins.

*Fig. 3. DISTANCE reworking of the architectural project designed by G.Perugini, A.Mauro, R.Celestino.*

The three projects are very different in their final shape. Although, each one’s aim is to solve the critical issues of the project area in its specific way, they are all based on a design process that finds its beginning on the study of important monuments and the changes they have caused to the areas they are placed-in. Once identified, these mutations became the bases of the projects by creating different shapes. The design assumes all the features of the place, gathering the continuity with the past and the tradition. Contemporary architecture can reveal the symbolic and synchronic value of the ancient monuments (Rossi, 1978).

The representation, introducing a certain level of abstraction for the environment and strengthening the lines and traces, exalts the property of each proposal while keeping a common level of reading, useful to allow a proper interpretation and evaluation of the three proposals.

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# Studies of the Early Christian Basilica of Christ of Jerusalem on the island of Kalymnos, Greece, through Terrestrial Laser Scanning

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***Keywords:*** *Laser scanning—point cloud—GPS—Kalymnos—basilica*

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doi: 10.11588/propylaeum.747.

## Introduction

With permission from the Ephorate of Antiquities of the Dodekanessa, a study permit was granted by the Greek Ministry of Culture and Sports in August 2016 (May 31st- June 9th, 2017) to conduct Terrestrial Laser Scanning (TLS) of a 5th century early Christian Basilica of Christ of Jerusalem on the island of Kalymnos.

The project involved an architectural study of the 5th to 6th century's triple-nave basilica of Christ of Jerusalem using TLS. The monument lies within the sanctuary of Delian Apollo, just outside the ancient settlement of Damos, in the area of Limniotissa, approximately 250 m west of the Chora of Kalymnos. The basilica was initially investigated and partially excavated by C. T. Newton in 1856 and later by M. Serge in 1937. The first systematic excavations at the site were conducted in 2007 and 2008 by the Greek Archaeological Service under the directorship of archaeologist Mihalis Koutellas.

The island features numerous early Christian basilicas, 26 in total (Karabatsos, 1994) but this particular monument was selected for study because it has been excavated and published; it is one of the earliest and best preserved monumental basilicas erected on the island in an area that was the political and religious centre of Kalymnos in antiquity; and it is constructed of spolia, quarried from the nearby temple to Apollo and other monuments of the sanctuary of Delian Apollo.

Once processing of the data is completed, it will be possible to identify architectural elements (in addition to those already confirmed) originating from the temple of Apollo and possibly other buildings in the sanctuary; enhance our understanding of the architecture and materials of construction; gain detailed knowledge of the form, shape and size of the basilica to an accuracy and resolution never achieved before at this site, including features missed in the earlier investigations (e.g. mason's marks); and provide a more accurate data base that will aid in the future preservation/conservation plans of the monument and assist the Greek Archaeological Service in the final publication of the site.

The goals of this project are to create a new dataset and compare these results (measurements, plans, drawings, orthoimages, models etc.) with those from past investigations and prepare a website to present preliminary results to the public.

## Scanning process

A Global Positioning System (GPS) receiver was used to establish the coordinates of the site and enable the point cloud to be tied to a national coordinate system. A portable three-dimensional terrestrial laser scanner, a Trimble TX5 (Faro Focus 3D) owned by the Dept. of Geodesy and Geomatics Engineering at the University of New Brunswick was used to digitally record the monument. The instrument sends out millions of laser pulses while rotating 360 degrees in a horizontal circle and +/-90 degrees in a vertical direction (Barber et al., 2014; Dare and Ahn, 2014). Once these pulses strike an object they are reflected back to the scanner which determines the 3D coordinates (x,y,z) of every point to an accuracy of a few millimetres. The basilica was scanned in sections with the help of small white spheres setup as boundary markers that served to stitch the images (a process called registration) to produce a coloured point cloud photo of the site using SCENE and Trimble RealWorks v7.2 software.

In total 79 setups were required to scan the monument and six billion points were amassed within eight days. On the first day, eight setups were conducted to scan the interior of the adjacent Chapel of Ypakoui. In total, during the first six days 69 medium resolution quick scans, of 15 minutes each, were conducted and on Days 7 and 8 sections were rescanned. A series of ten one-hour high resolution scans were also conducted in order to reveal details of smaller features that may have been missed (e.g., mason marks) and produce clearer images of the letters found on the inscribed blocks used to construct the basilica.

Despite using new equipment, issues surrounded the capture of the data from early on (Papaioannou et al., 2021). From the start mechanical problems occurred while scanning the interior of the chapel and the exterior of the entire monument. The interior was thus rescanned, and data analysis and processing of the point cloud of the interior were completed with difficulties. At the end of the first day while scanning the exterior of the chapel and basilica the scanner malfunctioned during the 2nd setup and stopped working during the 3rd setup. As a result, all data was lost. Trimble dealers in Greece, Canada and the USA were contacted in order to address the problem, new software had to be downloaded, two firmware upgrades were required including the renewal of the processing license and the problem was resolved within a few days. Data processing continued after returning to Canada. However, a computer malfunction resulted in the loss of all data processed at the site in June and later at home, including the aerial photographs and the video taken with the drone. However, the raw data was not lost.

In addition to the mechanical challenges other problems were also encountered during data acquisition. The bright sunlight made it difficult to view the scanner screen so a temporary covering (in this case a black plastic garbage bag) was required to cover the instrument. The time of day and angle of the sun also complicated matters as scanning the mosaic pavements and the east side of the basilica during the morning and midday, created shadows leaving certain areas in the shade, whereas others were too bright or not visible at all. Consequently, sections had to be rescanned.

Ideal conditions for scanning mosaics includes a cloudy day or direct sunlight from above in order to avoid shadows; the apse for example was rescanned in the late afternoon when the entire east side of the basilica was in the shade.

## Results

Processing raw data to create orthophotos and fly-throughs is time consuming (orthoimages and the flythrough completed for a site in Abdera required 346 hours of processing 10,000 images), while equipment malfunctions during the scanning and analysis processes can result in delays and the loss of many hours of work. All processed data was lost in the fall of 2017, but work has resumed on reprocessing the raw data. Fig. 1, Fig. 2 and Fig. 3 show images of the site created from the point cloud.

*Fig. 1 and Fig. 2. Aerial and angle view of point cloud of basilica of Christ of Jerusalem and Chapel of Ypakoui (© Peter Dare)*

*Fig. 3. Point cloud of exterior view of Chapel of Ypakoui (© Peter Dare)*

## Goals

1) complete the processing of the raw data (orthoimages), 2) obtain GPS information of the basilica (which may require a trip to Kalymnos) in order to geo-reference the TLS material and create

topographical plans, cross-sections, elevations and line drawings (with detailed elevation features), 3) create a relative comparison orthophoto of the site, 4) compare the new measurements by overlaying an existing plan of the basilica onto the TLS orthophoto, 5) use 3D digital images (with photorealist texture) to create digital elevation models, 6) create a website for the basilica and acquire permits from the Greek Ministry of Culture and Sports to launch the site, 7) develop visualization theories for scientific and public purposes, stemming from basic, technical and extended 3D digital models of the monument, and 8) create a virtual reconstruction and interactive visualization for the study of the basilica and the entire site (once a major pilgrimage centre).

## Summary

The TLS results of the basilica-chapel allow researchers to adjust and present an accurate plan of a significant early Christian basilica and ancillary structures. This highly accurate digital data base will aid in future studies involving 3D digital modelling for research, education, preservation/conservation purposes and final publication. TLS data will therefore contribute to our understanding of religious/public architecture of pilgrimage sites and serve as a preliminary study for future archaeological exploration of the entire site and other pilgrimage centres on the island and elsewhere.

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# Fact or Hypothesis?[1]

## Archaeological reconstructions based on 3D models created for documentation purposes by photogrammetry and CT scanning

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**Keywords:** *reconstruction—photogrammetry—CT scanning—popular science—3D models*

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### How can digital 3D models created for documentation purposes also be used as popular science reconstructions to clearly convey the difference between fact and hypothesis?

With the advent of new digital technologies such as laser scanning, photogrammetry and even CT scanning, the volume of data and 3D models for documentation purposes are also increasing (Campana and Remondino, 2016). The main aim of this work was to ascertain if it is possible to make these 3D models, which might not be as detailed as they could be, more accessible to non-professionals and to use them to create accurate reconstructions.

Experience has shown that an unproven hypothesis can be mistaken for a proven fact if the reconstruction is too realistic in nature (Schurz, 1995). Another task was therefore to find suitable imagery that would allow viewers to distinguish immediately between scientific fact and scholarly hypothesis.

### Case 1: Roman pottery kiln, a 3D model created by photogrammetric means

Several well-preserved Roman pottery kilns were discovered during an excavation at the site of the Vicus of *Tasgetium* on the south bank of Lower Lake Constance in 2000. The archaeologists decided to block-lift one of the more intact kilns for restauration in the laboratory and display at the museum. The kiln was placed in a corner of the museum with two sides concealed, one by a wooden panel, the other by the wall. In 2016 the decision was taken to record the exhibit by photogrammetric means in order to more accurately document it. The 3D model generated was incomplete on two sides due to the exhibition situation described.

*Challenges posed by making the kiln and its workings accessible to the general public:*

Since the 3D model of the kiln was incomplete and the model by itself, and particularly its original function, is not easily recognisable to a non-professional, some artistic adjustments had to be made.

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Knowing that a three-dimensional reconstruction could lead viewers to believe that the kiln's appearance was scientifically proven because it would look like a 3D scan of an intact kiln, the reconstructed parts in the 3D model were depicted in a completely different style and medium (Schurz, 1995). The medium that was eventually chosen was a short animation showing the bare rendering without any reconstructions followed by the reconstructed parts faded in as transparent pencil drawings. This resulted in an interesting mix of two diametrically opposed creative means of expression, photorealistic rendering and pencil drawing, which, it was hoped, would ensure that the distinction between documented fact and hypothetical reconstruction would immediately be made.

a b c

*Fig. 1. The different stages of the recovered pottery kiln a) during installation in the museum; b) the bare 3D scan, screenshot from the final animation; c) the reconstructed pottery kiln, screenshot from the final animation (© AATG).*

**Case 2: Block-lifted early medieval features, 3D models created from CT scans**

In 2013 a Merovingian-period cemetery with over 130 graves was discovered on the outlet from Lower Lake Constance. Due to time constraints and difficult weather conditions the decision was made to block-lift the delicate features. Shortly after the recovery of the features, CT scans were taken of about 40 of the gypsum blocks.

In 2018 the CT scanning data were reprocessed in order to document the artefacts and their locations during excavation in the restoration laboratory.

*Challenges posed by making a grave or traditional costume accessible to the general public:*

Because the CT scans were taken in a hospital, the density settings of the scanner were adapted to record recent material (Frey et al., 2014). This raised additional problems in that the settings were not ideal for documenting corroded metal or partially decomposed material. The 2D sectional views, on the other hand, were sufficient as documentation aids during the excavation of the individual blocks. However, the 3D models that could be generated from the scans exhibited a low resolution.

The same reasons as cited for case 1 led us to decide that the depiction of the grave and the reconstruction of the Merovingian person in traditional costume should not be too realistic. The problem, however, was that a layperson would find it difficult to understand a 3D model generated from a CT scan. The arrangement of the objects and only partially preserved bones would cause confusion. Single sectional images of CT scans are even harder to decipher for the general public. It was therefore decided that the exhibit should first explain why and how CT scanning is used in archaeology, so that the 3D model generated would be easier to understand. Individual objects that could clearly be identified on the CT scan with the help of reference artefacts were selected and shown in juxtaposition with the hypothetical reconstruction. The blocks have largely been left intact and the objects have not yet been excavated. By juxtaposing the 3D models generated from the CT scans with their reconstructions, viewers are free to independently interpret them.

The resulting artwork (Fig. 3) was longlisted for the 2018 international *KANTAR Information is Beautiful* Award.[3]

a b c

*Fig. 2. The CT data at different stages; a) sectional view; b) 3D model of the metal artefacts generated from a CT scan; c) 3D model of the metal artefacts with a superimposed transparent 3D model of the entire gypsum block generated from a CT scan (© AATG).*

*Fig. 3. The final layout of the artwork on three backlit acrylic glass plates. (© AATG).*

## Conclusion

When processing 3D data recorded for documentation purposes, the best prerequisites are given to distinguish between fact and hypothesis in a popular science reconstruction, since the documentation should record the pure facts. For the reconstruction it is recommended to differentiate the design from the 3D model of the documentation, for example by choosing a different design medium. Furthermore, sequences of images can help to explain the exact facts and circumstances of the documentation or reconstruction and thus give the viewer scope for his or her own interpretations.

3 https://iibawards.herokuapp.com/showcase/3293-scanning-arnegund, (Accessed: 28 May 2019).

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# The VR Museum for Dunhuang Cultural Heritage Digitization Research[1]

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***Keywords:*** *VR Museum—Dunhuang Mogao Caves—Cultural Heritage Digitization*

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## Introduction

Dunhuang Mogao Caves are one of the most best-known Buddhist heritage sites in China, it's famous for the mural and sculpture of Buddhist art spanning a period of 1,000 years. Along with Longmen Grottoes, Yungang Grottoes and Dazu Rock Carvings, it is the remains of ancient Chinese Buddhist culture. (Jinshi, 2000)

For decades, at the initiative of the Dunhuang Research Academy, researchers, and scholars from all over the world have conducted a variety of practical research of digitization, exploration, and experimentation.

The *Theories and methods of digital protection of cultural heritage research project* was conducted with the National Basic Research Program of the People's Republic of China. It was an interdisciplinary research project for Dunhuang Mogao Caves. During the research process, the project team launched the digital modeling work based on SLAM technology, the mural color inversion research based on chemistry experiment, etc.

This VR museum is a practice of how to build a research project into a cultural consumer experience product for the general public. It brings together visual and auditory elements and shows murals from the Buddhist grottoes of Dunhuang from various perspectives.

## Design goals

A museum is a place for humans to conserve collections, communicate information, encourage people thinking and educating each other. "Today, the museum in modern society has acquired a significantly broader public role than its early predecessors" (Awoniyi, 2001) However, for this Dunhuang VR Museum, there is no real-world museum corresponding to it. It's a virtual museum containing the digital copies of cultural heritage objects, recording and reproducing the process of scientific research of this resources in an interactive way, and expecting to spread and share these virtual exhibits more broadly though VR App stores on the internet.

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This Dunhuang VR Museum is a multimodal platform for the presentation of digitized cultural heritage. This presentation combines virtual reality and augmented reality, lives up even the most demanding artistic criteria, and offers both the general public and Dunhuang specialists an immersive experience that complies with both scientific and artistic standards.

The design goal of creating this platform is as follows:

1. Digitize the Caves: Recording the three-dimensional data and the physical space information before these actual caves are further damaged.
2. Visualize scientific research results: Provide professional audiences with specific detailed contents; also make it much easier for the general public to understand;
3. Achieve an experience: Create alternatives to the real caves, design an immersive experience for audiences who don't have a chance to enter the real one;
4. Extend the contents accessibility: Extending the material properties of cultural heritage, making its cultural communication behavior break through the limitations of space and time.

## Design process and methodology

This VR Museum simulated a life-size museum in VR Head-Mounted Display. With the virtual reality interaction, audience can get an experience of walking in a real-size museum space. The interior space design uses natural form and color to build. The high precision 3D models are reconstructed by using photogrammetry and laser scanning technology. They are the main content which can be viewed, manipulated, adjusted, and can even change the look of different eras. Another benefit of virtual museum is that all the virtual devices can be set to automatic adjust into different style to cater to the audience.

*Fig. 1. photo of Dunhuang 159 Cave (© Authors).*

*Fig. 2. Screenshot of Dunhuang VR Museum (159 Cave included) (© Authors).*

For extending the right to access for different audience groups, the project is not only available in HMD, but also can be viewed on desktop and mobile devices. If using mobile devices that support the latest WebXR capabilities, the audience can also experience the augmented reality content of this museum.

The deep immersive application for HMD is developed in a game engine like Unity and Unreal Engine, and it is suitable to Oculus Rift and HTC Vive Head-Mounted Display. For better user experience, the design process follows four aspects of "Freedom of operation", "Immersion", "Comfort of play", and "Picture quality" that are examined to clarify which type of virtual museum would be suitable for any specific user's needs (Takeuchi et al., 2019).

Through the summary in Dunhuang Cultural Heritage Protection research, this practice gives out a low cost, easy to use and comfortable experience of mixed reality application development framework and developed a web-based virtual reality museums system.

## The Way Forward

Contemporary museums are increasingly becoming digital. With access to digital technology, the role of museums as cultural heritage has been strengthened. They are nowadays considered as a high priority for communication and play a central role in making culture accessible to the mass audience.

Due to the novel interactive mode and immersive experience, the general public has a strong interest in augmented reality, virtual reality, and mixed reality. With the decrease of the cost both in technology and hardware, the demand for AR & VR applications increased rapidly. It can be expected that the demand for virtual reality museums will increase significantly.

Of course, the VR exhibition method does not have to be isolated. The inclusion with images, video, sound, and tangible interaction, will make the VR museum’s communication strength stronger and increase the participation of the public.


*Fig. 3. The audience is experiencing the virtual cave (© Authors).*


*Fig. 4. VR Integrated with Multimedia used on for Dunhuang Cultural Heritage Exhibition (© Authors).*

## Acknowledgment

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# A crypt in the wood

## Digital survey of the ruins of St Salvatore's Abbey in Giugnano, Italy

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***Keywords:*** *Digital Survey—architecture—3D laser scanner—medieval archaeology—abbey*

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### Introduction

This study was conducted in a research project about the current state of the Abbey of St Salvatore in Giugnano, using cutting-edge methodologies in the field of architectural survey. The ruins are in the middle of a grove of holm oaks, on the property of the Agriturismo San Guglielmo, along the Bai river in the Bruna valley. The location, close to a stream and in an area rich in raw materials, is not to be considered casual, in fact, besides being a place of prayer, it was also the site of intense metallurgical activity. The relationship between the viability and the position of the monastery is close, in fact, near the abbey, an important crossroads was situated where the two main routes of the Grosseto plain passed towards the hinterland.

### Historical Analysis

The monastery has had a rather troubled history. Founded under the Benedictine order in the XIII century, it became a grangia of the Cistercian abbey of San Galgano in Monte Siepi. The hermits of Saint Augustine acquired its jurisdiction at the beginning of the XIV century. However, within a few years, it was deemed a losing bargain and put back on the market (Farinelli and Marrucchi, 2005). From this moment on there are few information about San Salvatore a Giugnano, probably due to a gradual decline of the religious and metallurgical activities after the abandonment by the monastic order. Today the crypt and the gothic Aula are badly deteriorated, so it is necessary to secure the structures and build a new entrance to the crypt.

### 3D Documentation

After having acquired the historical knowledge, the work proceeded with a contactless 3D acquisition survey: a measurable 3D model of the remains has been obtained using a laser scanner (model Faro X330). The data acquisition was carefully designed to avoid shaded areas or loss of information. The survey was completed by a photogrammetric campaign performed with Reality Capture software.

The result of the laser scanner survey is a 3D discontinuous model that comes from a progression registered scanning by specific software (AutodeskRecap_Pro) creating a point cloud. The 47 acquired scans have been processed in this semi-automatic software that recognizes and collimates the target and homologous points into a single 3D measurable model. The next step was to merge the dimensional Recap model with the photogrammetric Reality Capture's one, to finally provide a highly detailed – chromatic textured representation of the ruins. That has been achieved with the following process:

- using *Align Images* on the photos obtained during the photogrammetric campaign, it has been created a dense cloud of coloured aligned points.
- build a triangular mesh.
- apply a coloured texture to the mesh, obtaining a continuous and textured 3D model (Fig. 1).

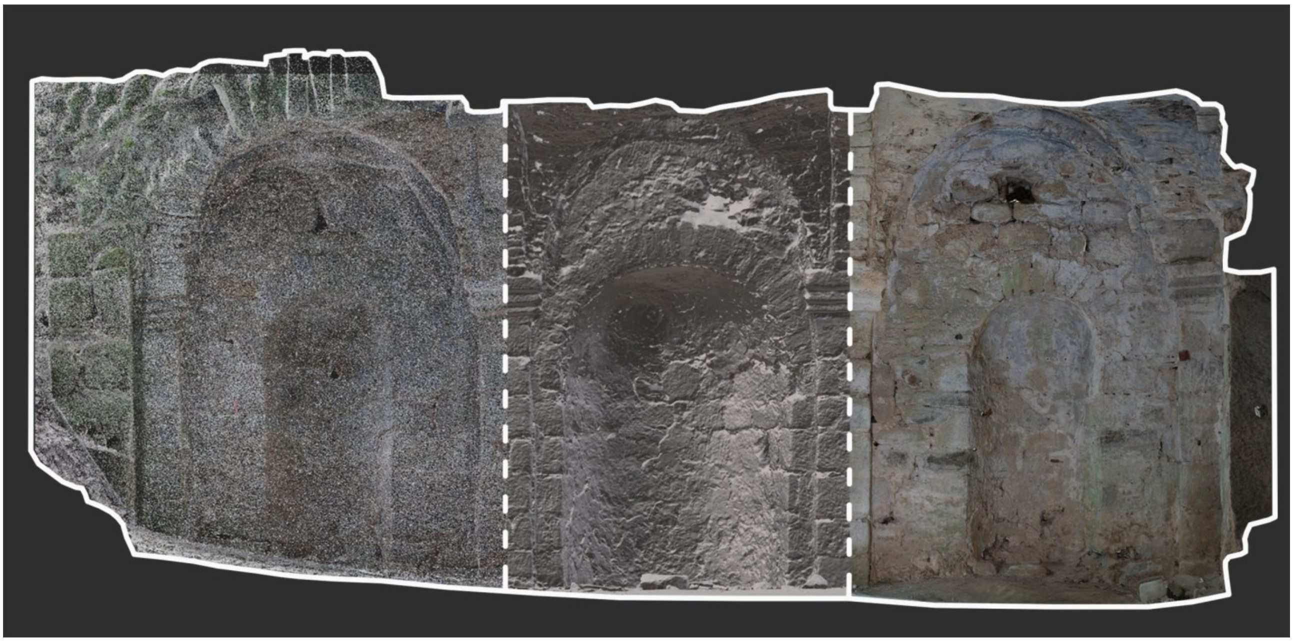

*Fig. 1. Transition from the pointcloudmodel to a mesh textured model (© S. Maggi)*

Alongside the 3D survey an in-depth study about the historical and territorial context has been carried out by consulting various indirect sources preserved both in private and public archives. This was followed by an in-depth study of the materials and technologies applied in the construction phase, seeking the unit of measurement applied to the construction of the abbey and comparing it with other similar cases both at regional and extra regional level (Rutishauser, 1993). It was therefore possible to infer that the reference unit of measurement for the construction of the Roman crypt and of the Gothica aula was the Florentine arm (0,5858 m) and its half both (Fig. 2).

Of the monastery, to date, only the underground Romanesque crypt have been preserved, together with some portions of perimeter walls of a rectangular Gothic Aula of later date. On the surface, hidden by vegetation, there are faint traces of walls that can be traced back to the church. The crypt today appears as completely underground space, which can be accessed only through an open breach on the ceiling of the vault (Fig. 3). The plan has a rectangular design extended by a large semicircular oriented apse, with three niches, now obstructed. The room is divided in three naves and the ceiling is realized by a system of cross vaults which is supported by four columns. Every column capital has a different decoration.

The Gothic Aula has a rectangular plan, but only two outer walls still exist. Probably the entrance of this church was in the East wall, some traces of an arch springer are visible in this area (Brogiolo and Cagnana, 2012).

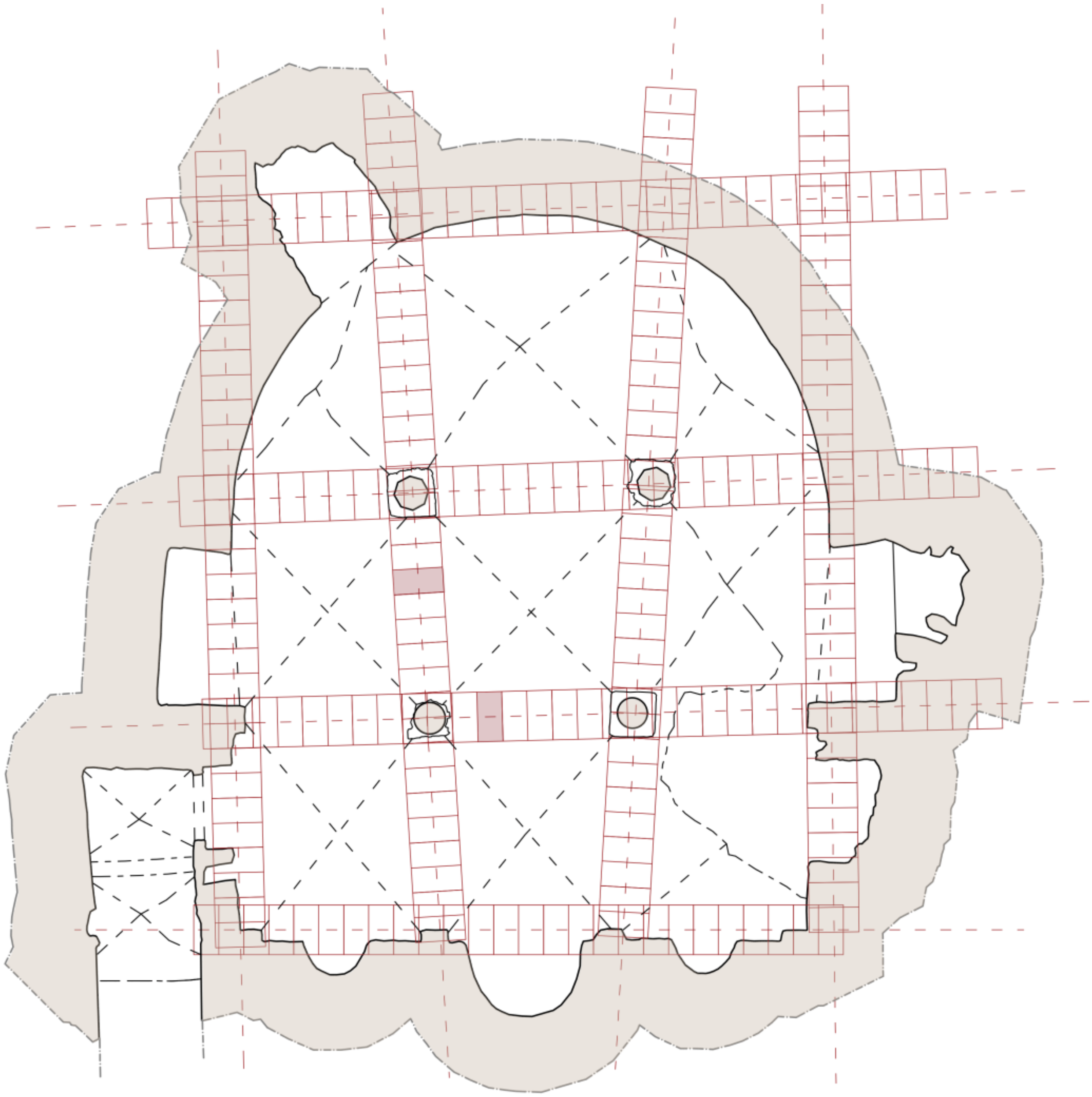

*Fig. 2. Study of the unit of dimensional layout of the crypt (© S. Maggi)*

## Conclusion

After a sound knowledge was acquired the study moved on to analyse the strengths and weaknesses that affect the building and the place where it is set, trying to propose solutions on a critical issue scale. The work was completed by defining some design guidelines for the future protection and a possible new use, supported by smart and modern communication strategies.

*Fig. 3. View from the inside of the crypt (© S. Maggi)*

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# Digital survey as a diagnostic tool

## A model for the tower of the Castle of Cerretaccio

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***Keywords:*** *digital survey—building history research—medieval tower—3D model—digital reconstruction*

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## Abstract

In the world of architecture, in particular closely linked to the architectural design of new constructions, 3D models have always been used as a method of deepening the design vision. In this case, the model constitutes the connection that exists between the 2D design and the real construction, representing the anticipated and editable reproduction of the finished object.

In restoration and in the study of existing heritage, the 3D model, intended as a product of processing data obtained from digital survey (point clouds and photographic mesh), can be a tool not only of accurate representation, but also the communicative link between what the building is today and what it hypothetically has been. What the model represents in the architectural design, that is the projection of the idea in the object created, in the restoration becomes the tool of projection in the past.

This type of approach associated with a stratigraphic study and a physical-chemical analysis of the materials, is particularly applicable in all cases where a building, subjected to different kind of stress, has suffered a collapse of the structures, and when the numerous ruins in the terrain are particularly fragmented and decomposed and are therefore not easily identifiable.

Given these considerations, it is interesting to present a case study where this method is of essential importance in the analysis of the collapse dynamics of the building.

The Castle of Cerretaccio lies, immersed in the woods of Chianti, in the Municipality of Castelnuovo Berardenga. The castle, dating back to the 11th century, represented a bastion of invaluable importance in the history of the city of Siena. Despite lots of Florentines assaults, the castle never seemed to capitulate to enemy attacks and was able, in all circumstances, to repel them to guarantee the defence of the Sienese territory to which it had always been faithful.

Although the building assumed a great fame in the period of the first Sienese-Florentine war, in a few centuries it turned into a mass of ruins which, subjected to degradation, have transmitted very few fragments of the building to our days. The cause of this demographic and architectural

interruption is to be found in the episode of the collapse or demolition of the central tower of the castle, a symbol of the power of the family that owned it, the Cerretani, and an essential point of sighting and defence in the case of enemy sieges.

The impact of the tower did not occur only against the ground but destroyed all the structures around it. This, according to historians, was the beginning of the ruin of the castle. The population abandoned it, probably pouring into some nearby centre and the site was never repopulated. Around this episode of such significant change in the events of the settlement and its material structures, two contrasting versions were defined.

According to a manuscript written by Don Virgilio Peruzzi the destruction of the castle is traced back to episodes extraneous to the military events that were affecting the city of Siena. In fact, according to this version, some exiles from the Sienese prisons took possession of the castle, carrying out raids and crimes of all kinds in the surrounding territory. The Sienese Republic then decided to intervene by engaging 100 “sappers” who had the task of demolishing, precisely, to “sap” the tower. Therefore, this procedure involved removing the walls at the base, replacing the empty walls with wooden beams that, once consumed by the fire, gave way, causing the building to capitulate.

The other version instead, supported by Giovanni Antonio Pecci believes that the destruction dates back to the last war events of Siena, around 1555. According to his writings, in fact, the castle was destroyed in the last war of Siena, clearly by the Habsburg Empire that ended a decommissioning enterprise begun years earlier.

However, between these two versions, by consulting the historical INGV (Istituto Nazionale Geofisica e Vulcanologia) databases, a third one could emerge, even more significant, not reported by historians, but worthy of analysis. In fact, it is credible that the large earthquake that struck the Chianti area in 1558 caused the tower to collapse and led to the destruction of the castle.

This is one of the most evident cases in which the digital survey and therefore the production of a 3D model could become not only a representative tool but rather an essential diagnostic tool. By implementing a backward procedure, starting from the various fragments of the tower lying on the ground and going to reassemble them, up to virtually reconstruct (or physically using a scale model) the original model of the tower, it will be possible to highlight any deficiencies consistent in the foundations, fractures that can be traced back to the seismic action or to the war activity or possibly aspects never taken into consideration.

This disassembly and reassembly method is an elementary process, of easy intuition, but it can lead to deductions that are anything but immediate, demonstrating how digital surveying can and must therefore represent, for the study of the existing heritage, not only a passive means of representation of the state of affairs but rather going to play the active role of diagnostic tool.

## Figures

*Fig. 1. Tower section. (© A. Maramai)*

*Fig. 2. Some fragments of the tower. (© A. Maramai)*

*Fig. 3. Digital survey campaign. (© A. Maramai)*

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# Harbour infrastructures from different pasts

## The case of the double abandoned Silos in Livorno, Italy

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***Keywords:*** *Digital Survey—Port—Photogrammetry—3D laser scanner—Concrete*

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## Abstract

The silos in the Harbor of Livorno, central Tuscany, Italy, represent an industrial memory. They have a complex story behind. The first one was built for the storage of cereals at the beginning of the XXth century. It is a typical example of industrial food storage operated in those years (Vaquera Pineiro, 2010). On October 28th 1918 the Municipality of Livorno signed the concession authorizing the *Società Silos Livornesi* from Genoa the construction of a first silo. The courtyard began in May 1921 and ended in 1924, the silo started its functioning in the same year. The design of the building was optimized for a certain number of “automatic” operations, with a high level of technology for that time, like mechanical storage and unloading, possible remote handling (cleaning, aeration, mixing). It gave the possibility to store cereals, seeds, legumes and other types of goods. This first building, made in reinforced concrete, was structured in two adjacent and communicating parts: one for the storage cells and one for the accessory services, in which there were some offices, the stairs and the vertical connections of most of the mechanisms for handling grains. The part destined to storage itself has a square plant with a side of about 27 metres, beveled on the South corner, and is about 35 metres high. The cells collecting the wheat have a height of about 23.50 metres and are divided into four main types with different shapes:

- 24 cylindrical cells, with a diameter of about five metres and with a capacity of 488 cubic metres each (11,712 total cubic metres).
- 15 quadrangular cells, formed by the resulting interstices between the cylindrical cells, with a capacity of 188 cubic metres each and 2820 total cubic metres.
- 13 perimeter triangle cells, with a capacity of 52 cubic metres each and a total of 676 cubic metres and one special perimeter cell, with a capacity of 263 cubic metres.

Essential parts for the functional operations of the silo were the mechanical systems. The silo was equipped with an articulated group of machines allowing the movement of the cereals from and to

the cells and designed for the scope of preserving at the best this basic food component. One of the main machineries consisted of two large elevators that could slide along a metal structure extending to the southwestern end of the quay. On the elevators there were a series of conveyor belts, capable of handling one hundred tons of grain per hour, taking it directly from the holds of the ships alongside the quay.

Despite its massive industrial presence, this building is characterized by rich details, like for the pillars, realized with almost mannerist solutions, using a “gigantic order” design. The overall impression is the one of a monumental building with a strong and massive personality.

Thus, no matter the fascination coming from this very specific architecture, the existence of the building itself was put at risk by the events of the World War Two. In fact, in 1944, the Port of Livorno was bombed. The silo building was heavily damaged, but not destroyed. The front building loses one of the sides, while the silo suffered damage only in the upper floor. The top part of the stair tower was demolished, as well as a part of the building’s gables. Despite the bombings suffered by the port of Livorno, which was considered a strategic target, the Silo miraculously saved itself in its most significant parts.

In the second half of the XXth century the Silo was restored and expanded in the 60s with a new massive structure, duplicating the volume of the storage area. From this transformation -nowadays still a strong sign in the city skyline- the silos have been in operation for about 20 years, around the 80s the use of this structure was quitted. A progressive degradation of the two buildings began, with the newer parts suffering even worse decay than the original building.

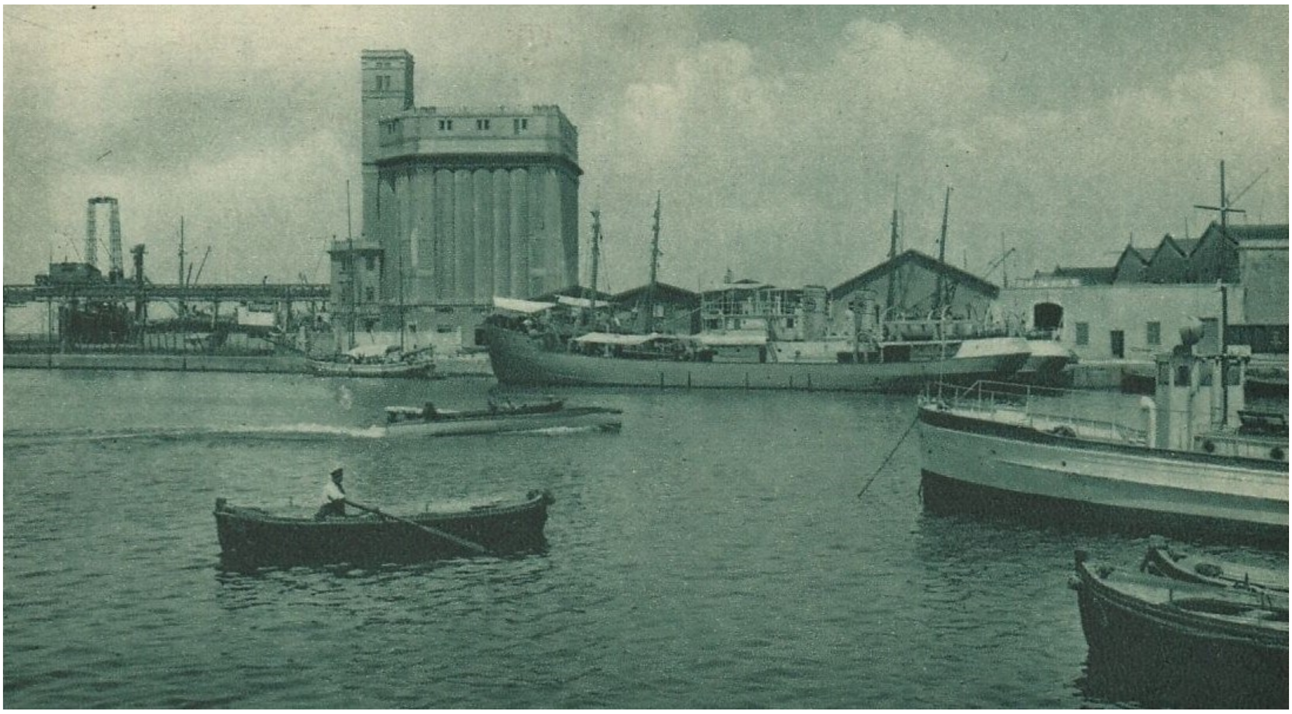

*Fig. 1. The Silos in 1941 (© Authors).*

*Fig. 2. The Silos in 2019 (© Authors).*

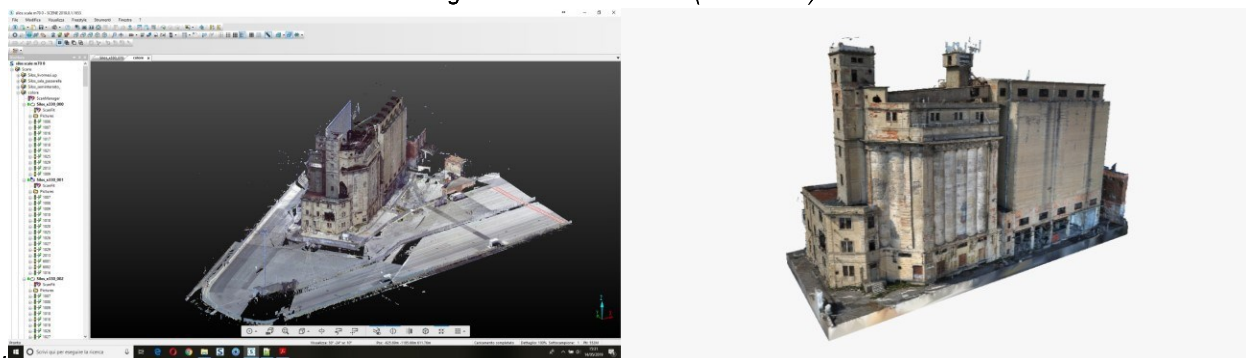

*Fig. 3. Digital Survey of the Silos in 2019 (© Authors).*

This ruined architecture keeps on fascinating the visitors and the people from the large ferries arriving all around the quay of the Silos from Corsica, Sardinia and other island and/or countries of the Mediterranean. The buildings capture the attention, and in time, they have been the subject of various studies, thesis, hypothesis about including them in an extended functional recovery of the port (Marchetta, 2004).

The place, taking a central position in the Harbor of Livorno, represents the heart of economy for the city. The building shows important structural damage and deteriorations. A first intervention should assume their correction as a priority. The proximity to the Fortress of Livorno increases its value as a tourist attraction: the guidelines for a project proposal should try to valorize the building, giving new life without altering its “industrial” aspect and exploiting such a strength to confer a new image to the city.

In 2019 a complete digital survey of the whole structure was operated using both 3D laser scanner and photogrammetry, creating the first accurate and updated survey of the building since its construction. The survey work was commissioned by the port authority and operated by and a team from the Team Area3D Srl; Livorno and a team from the Dipartimento di Architettura, University of Florence, coordinated by Prof. Giorgio Verdiani. The resulting 3D models and all its derived drawings are the base for a possible reasoning about recovery and regeneration. The contents of the poster proposed here will analyze this important industrial heritage, describing the specific workflow, the techniques and the procedures used to bring to the end the complex task of documenting a large and massive industrial building without losing a proper level of details on its machineries, decorative details, materials and signs of decay. A complete process from documentation to the challenge of urban regeneration will be presented to share and discuss the best practice in the approach to these kind of buildings/areas (Giugni et al., 1982; Stratton, 2000; Soriani, 2002; Kiib 2007).

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# (Re)tracing History without Boundaries

## A Common Digital Platform for Medieval and Early Modern Epigraphy

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***Keywords:*** *Medieval epigraphy—early modern epigraphy—digital epigraphy—searchable databases—TEI*

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## General issues

Over the course of the past few decades, a huge leap forward has been made in humanities, particularly in biography, due to the possibilities opened up by new technologies—although a lot more is left to be desired. Only a few years ago, a valiant attempt has been made to offer a project designed to overcome problems, related to different formats and data models of national biographical collections (BiograVIS). The BiograVIS project accurately pinpointed the problem that "archives have been translated and aggregated into comprehensive, partially structured research databases", but are still structured in such a manner that not every researcher from anywhere in Europe (or the world, for that matter) can freely access it and process it right away. Another similar COST project, "Reassembling the Republic of Letters" proposed a similar idea: to bring together raw material and process it in such a way that these large amounts of (mostly text) documents would be manageable for professionals as well as non-professionals to be processed in any way possible.

In a similar but unrelated field, the field of epigraphy, the problem is very much the same. Although the state of affairs is much more crude still—not Greek and Roman epigraphy, which has had a long scholarly tradition as well as the tradition of digital processing (see below), but first and foremost medieval and early-modern epigraphy, which has suffered, at least in some countries (particularly of the so-called former Eastern Block) a particular kind of neglect.

Although medieval and early modern epigraphy has a strong tradition of scientific attention in western European countries (it is noteworthy that this survey deliberately omits the rune inscriptions from the northern European countries and that of the English area), it lags behind in the field of digital processing and visualisations compared to Greek and Roman epigraphy. Considering the historical development of medieval epigraphy, the thesauri of inscriptions from Italy, Spain and Germany stand out. Studying inscriptions from the Italian countries has a particularly long tradition. Addressing the important Christian centres, the scientific organisation of the Monumenta epigraphica Christiana strongly hints at CIL. Lately, these publications have only intensified in number; one such example (among many) is Paola Guerini's Inscriptiones Medii Aevi Italiae (saec. VI–XII) II: Umbria, Terni

(Guerini, 2010). The medieval and early modern inscriptions, collected in Spain, are being systematically published in the so-called Corpus inscriptionum Hispaniae medievalium (cf. Martín López, 2014). Similarly, the medieval and early modern inscriptions, collected in the area of France, are published in the Corpus des inscriptions de la France médiévale.

One of the must exemplary approaches to medieval and early modern epigraphy is the extensive German corpus Die Deutsche Inschriften (DI; the Die Deutsche Inschriften is also online: http://www.inschriften.net/); the academies of science in Berlin, Düsseldorf, Gottingen, Heidelberg, Leipzig, Mainz, Munich together with the Austrian Academy of Sciences in Vienna undertook a massive task of publishing a series of medieval and early modern inscriptions occurring in the entire German-speaking area. Since 1942 when the first volume was published, more than 90 volumes have been published up to this day (cf. Jäger, 2012; Zahn, 2014). Individual volumes address inscriptions from one or more cities in a particular area. During the course of publishing the DI, a methodology for the description of medieval and early modern inscriptions was devised. Outstanding works of this kind are, among others, the papers by Fritz V. Arens and Konrad F. Bauer the "Mainz Inscriptions—and Introduction to the German Epigraphy" (Arens and Bauer, 1945) and Austria's Walter Koch "Epigraphy—Instructions for the Transcription and Classification of Script in the medieval and early modern inscriptions" (Koch, 1975). Another important work by several authors is "German Inscriptions. Terminology for the Description of Script" (Deutsche Inschriften: Terminologie zur Schriftbeschreibung, Wiesbaden 1999), which was written by the associates of the DI based on the German and Austrian inscription materials within the series' time scope, addressing the scripts occurring from the early middle ages to the late 17th century. One of the most systematic manuals for medieval and early modern epigraphy was written by Rudolf Kloos (Kloos, 1992) in 1980. The manual was later reprinted. He assembled the basic bibliography and a survey of corpuses, but above all, he tried to forge sound methodological guidelines (Kloos, 1992, pp. 87ff.), which will serve this project to some extent; his "Introduction to the Medieval and Early Modern Epigraphy" (Einführung in die Epigraphik des Mittelalters und der frühen Neuzeit) is therefore indispensable.

As of late, corpuses similar to Die Deutsche Inscriften are being assembled in some eastern European countries, such as Slovakia (Corpus inscriptionum Slovaciae, cf. Čovan, 2016), whereas others, e.g. Poland, have featured such collections for decades (Corpus inscriptionum Poloniae). In Poland thematic monographs on medieval and early modern inscriptions are being published at an accelerated rate (Kotlowski and Starek, 2014; 2015).

### A short case study…

This is all find and well. However, the following short case-study will tell us that a concerted and big effort needs to be invested in order to come even closely to the efforts invested into harmonizing vast quantities of data and making it available to researchers worldwide.

When approaching e.g., 16th century humanists involved in an European-wide network of scholars, diplomats and politicians, one stumbles upon the name of one Pier Paolo Vergerio "the Younger" (1498–1565). The man left a heavy trace in the post-Reformation European politics, yet precious little epigraphic material is left behind. Or is it? Only a handful of major works have been published about him in recent decades (e.g. Jacobson Schutte, 1977), yet all of them neglected an important piece of his personal history—an inscription still extant in the Koper cathedral, only hidden from "uninvited" eyes:


*Fig. 1. Inscription of the Vergerii, Koper cathedral (© G. Pobezin).*

This very interesting inscription with its striking *damnatio memoriae* failed to be entered into any epigraphical database—much like the one in Tubingen recording his death in 1565. For any researcher of humanism and humanists, particularly the ones of such high profile, these epigraphic sources are an indispensable source.

A tool for processing these sources is needed: advanced search options and visualizations facilitating the processing, analysis and even finding data in a large, sometimes not even registered data. To enable access to this data and the analyses thereof, a concerted effort of several stakeholders from several countries would be needed, which could build, develop and contribute to an all-European visual information portal for the recording, processing, exploring and equipping epigraphical records with metadata that would allow professional and non-professional researchers a simple and comprehensive access.

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