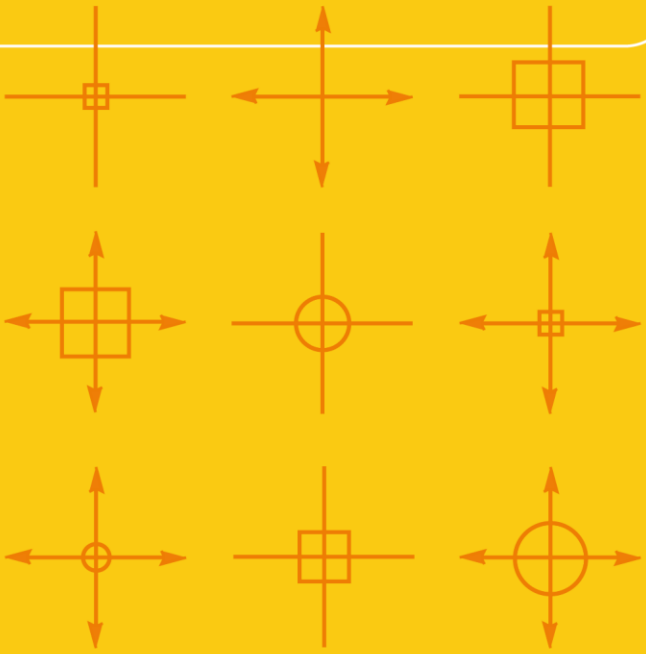
CHNT 25

International Conference on
Cultural Heritage and
New Technologies
November 4–6, 2020

Artificial Intelligence
New Pathways Towards Cultural Heritage

Proceedings of the 25th International
Conference on Cultural Heritage and
New Technologies 2020.
CHNT 25, 2020

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



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CHNT

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

Edited by
Museen der Stadt Wien – Stadtarchäologie

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Bibliographic information published by the Deutsche Nationalbibliothek

The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie;

detailed bibliographic data are available in the Internet at http://dnb.dnb.de.

The electronic open access version of this work is permanently available at https://www.propylaeum.de

urn: urn:nbn:de:bsz:16-propylaeum-ebook-1045-1

doi:https://doi.org/10.11588/propylaeum.1045

Published by
Heidelberg University/Heidelberg University Library
Propylaeum – Specialized Information Service Classics
Grabengasse 1, 69117 Heidelberg, Germany
https://www.uni-heidelberg.de/en/imprint

Editor: Museen der Stadt Wien – Stadtarchäologie

Chief Editors: Wolfgang Börner, Hendrik Rohland

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Cover illustration: Christine Ranseder, Lina Karner

eISSN 2510-8182

ISBN 978-3-96929-157-3 (PDF)

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Preface

Artificial Intelligence – New Pathways Towards Cultural Heritage

We know how to digitize our heritage, so what is the next step? Making our Cultural Heritage more accessible to the general public and fellow researchers, and even accessible when it is not there anymore.

In recent years, the application of Artificial Intelligence (AI) approaches has increased rapidly in cultural heritage (CH) management and research. A main driver is the availability of remote sensing data, allowing to detect new archaeological sites and to monitor the preservation of known monuments. Due to advances in computer power and a wide range of free machine learning tools, large amounts of remote sensing data can be processed automatically for CH purposes instead of covering only small areas by expert inspection.

But AI may also be applied for other tasks in cultural heritage research including automated classification of archaeological pottery or bones from excavations, classification of object images in cultural heritage collections, symbol and text recognition in ancient inscriptions, detecting relevant terms (often consisting of several words) in site report repositories with limited metadata, mining historical texts, expert systems in restoration, knowledge representation by ontologies, simulation of crowds in buildings (past and present: e.g. museums, prehistoric caves, palaces). Mixed reality apps using AI technology as well as Ambient Intelligence approaches support the creation of new pathways towards Cultural Heritage for the public. Cultural Heritage may also benefit from robotics with integrated AI applications, e.g. vehicles searching for sites in inaccessible areas such as unmanned submarines used for detecting archaeological remains in lakes and the sea.

"Is it possible to build a machine to do archaeology? Will this machine be capable of 'interpreting' and 'explaining' cultural heritage?" (Juan A. Barceló, Computational Intelligence in Archaeology. State of the Art, CAA 2009)

This proceedings are the result of the 25th CHNT conference. This conference was about showcasing best-practice AI applications and the creation of the required data, but also about discussing the potential and limits of various AI approaches such as the amount of labelled data required. Furthermore, as this was the 25th anniversary of the conference, some personal reviews of the history of the conference and the topics discussed throughout the years have been included in the programme. We hope that the diverse papers and abstracts in this volume inspires the reader to further explore the potential of digital technology and AI in Cultural Heritage.

The Editors

Keynote

Virtual and Augmented Reality for Maritime Archaeology

A Case Study from the iMARECULTURE Project

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Abstract: Underwater cultural heritage sites are widely spread into the Mediterranean Sea and are not accessible to the public due to their environment and depth. Digital technologies have been used in the past, but they are very limited in terms of what visitors can see and how they can interact. Recent advances in virtual reality and augmented reality provide a unique opportunity for digital accessibility to both scholars and public, interested in having a better grasp of underwater sites and maritime archaeology. The project iMARECULTURE (Advanced VR, iMmersive Serious Games and Augmented REality as Tools to Raise Awareness and Access to European Underwater CULTURal heritage) focused in raising European identity awareness using maritime and underwater cultural interaction and exchange in Mediterranean Sea. This paper presents results from iMARECULTURE project in respect to virtual and augmented reality applications for underwater environments. In terms of virtual reality, a serious game that aims in teaching maritime and archaeologist students the main principles of 'site formation', 'surveying' and 'excavation'. Moreover, a novel augmented reality underwater application is presented which can detect square markers in poor visibility conditions as well as serve as virtual guide for divers that visit underwater archaeological sites.

Keywords: *Virtual Reality—Augmented Reality—Maritime Archaeology*

CHNT Reference: Liarokapis, F. (2022). 'Virtual and Augmented Reality for Maritime Archaeology: A Case Study from the iMARECULTURE Project', in Börner, W., Rohland, H., Kral-Börner, C. and Karner, L. (eds.) *Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020.* Heidelberg: Propylaeum.
doi:10.11588/propylaeum.1045.c14473

Introduction

Underwater cultural heritage sites are widely spread into the Mediterranean Sea and are not accessible to the public due to their environment and depth. Photos and surfaced artefacts exhibited in maritime museums provide fragmented aspects of such sites, but this is all visitors can see (Liarokapis et al., 2017). Digital technologies have also been, randomly used, in museum exhibitions, as a supplementary information source, but not always very successfully (Skarlatos et al., 2016; Bruno et al., 2017). Recent advances in virtual reality (VR) and augmented reality (AR) provide a unique opportunity for digital accessibility to both scholars and public, interested in having a better grasp of underwater sites and maritime archaeology.

The project iMARECULTURE (Advanced VR, iMmersive Serious Games and Augmented REality as Tools to Raise Awareness and Access to European Underwater CULTURal heritage) focused in raising European identity awareness using maritime and underwater cultural interaction and exchange in Mediterranean Sea. The aim of the project was to bring inherently unreachable underwater cultural heritage within digital reach of the wide public using virtual visits and immersive technologies (Skarlatos et al., 2016; Bruno et al., 2017).

This paper presents results from two distinctive applications in underwater VR and AR for maritime archaeology. In terms of VR, a serious game that aims in teaching maritime and archaeologist students the main principles of ‘site formation’, ‘surveying’ and ‘excavation’. Moreover, a novel AR underwater application is presented which can detect square markers in poor visibility conditions as well as serve as virtual guide for divers that visit underwater archaeological sites.

Background

Underwater Virtual Reality

In 2017, an immersive virtual underwater visit in Mazotos shipwreck site was presented allowing for an interactive exploration of the shipwreck and its environment such as plants, fish, stones, and artefacts (Liarokapis et al., 2017). In 2018, a diving simulation in VR was proposed allowing users to experience a historical–cultural context with information regarding the flora and fauna of the underwater site (Bruno et al., 2018). The same year, an immersive VR learning application for teaching the essentials of the underwater excavation based on a realistic sand simulation was proposed (Kouřil and Liarokapis, 2018). In 2019, an educational VR application aiming to aid the future marine archaeologists with the basics of photogrammetry was developed showing that the gamification techniques allowed the creation of accurate measurements to be made (Doležal et al., 2019).

A marine ranch visualization application for the tourism industry simulated the behavioral characteristics and environment of fish swarm in virtual marine ranch to shorten the distance between users and marine ecology (Liu et al., 2020). Moreover, search techniques for discovering artefacts in underwater environments were proposed in the form of a serious game and a VR game (Liarokapis et al., 2020). Recently, a very simple underwater museum using VR was proposed based on point cloud and rig animation (Manju et al., 2021). However, the work seems to be preliminary, and it was not evaluated with users. Another study compared three important elements of VR such as presence, vection and visually induced motion sickness among 30 participants experiencing VR while standing on the ground or floating in water (Fauville et al., 2021). Vection was significantly enhanced for the participants in the water condition, but no differences in visually induced motion sickness or presence were found between conditions.

Underwater Augmented Reality

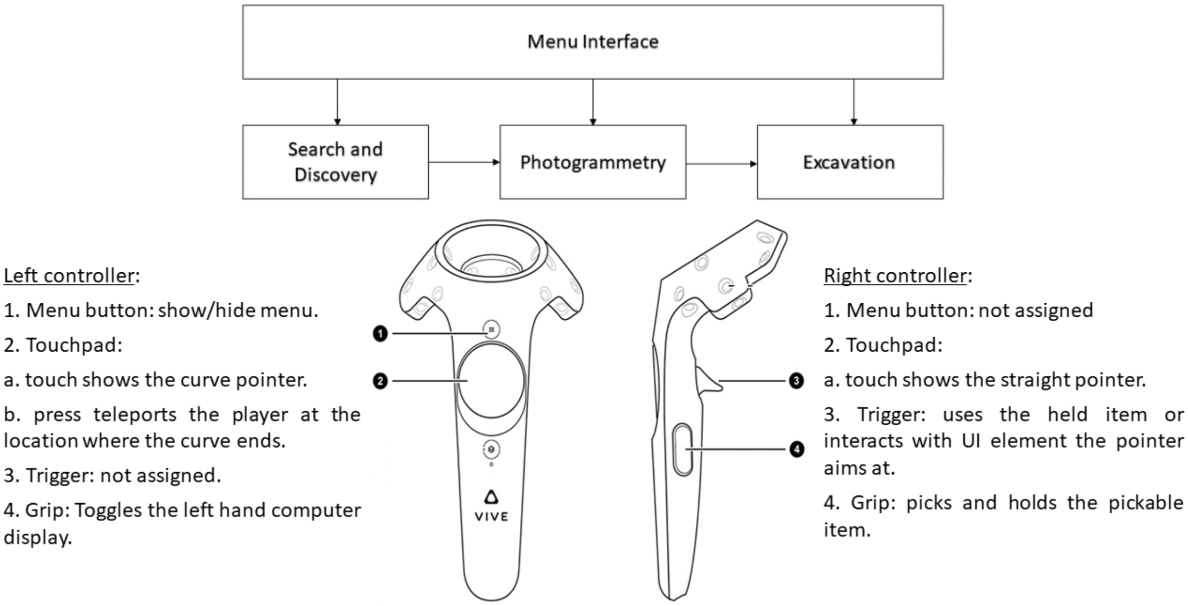
In terms of underwater AR, two systems were proposed in 2009. The UWAR system provided visual aids to increase commercial divers’ capability to detect, perceive, and understand elements in underwater environments (Morales et al., 2009). In another approach, AR was experimentally demonstrated in a swimming pool where it generates visual representations of virtual 3D scenes (Blum et al., 2009). AR was also developed for remotely operated underwater vehicles (ROV) and could be used as navigational and manoeuvring aid as well as prior mission training (Toal et al., 2010). In

2012, an underwater-computerized display system with various sensors and devices conceived for existing swimming pools and for beach shores, associating computer functions, video gaming and multisensory simulations was proposed (Bellarbi et al., 2012).

A year later, an underwater AR system focused on both recreational and commercial divers during navigation providing a fish identification scheme (Brown and Wang, 2013). The first multi-player underwater AR experience for swimming pools focusing for recreational and educational purposes was presented in 2013. In 2016, an evaluation of the same application with 36 kids was presented (Oppermann et al., 2016). In 2018, a new method for AR tracking was introduced based on white balancing (Čejka et al., 2018). The method enhances underwater images to improve the results of detection of markers for AR. Recently, two novel solutions for underwater AR were presented: a compact marker-based system for small areas, and a complex acoustic system for large areas (Čejka et al., 2021).

Virtual Reality Excavation Game

The VR excavation game consists of three components including: search and discovery (Liarokapis et al., 2020), protogrammetry (Doležal et al., 2019) and excavation (Kouřil and Liarokapis, 2018). The architecture of the VR serious game including the controllers is presented in Figure 1. The game is controlled through a menu and VR controllers. It has two models of operation. In the first one, each component must be completed in a sequential manner. However, in case that a player wants to skip a component can jump directly to a particular component through the menu.



Left controller:

1. Menu button: show/hide menu.
2. Touchpad:
a. touch shows the curve pointer.
b. press teleports the player at the location where the curve ends.
3. Trigger: not assigned.
4. Grip: Toggles the left hand computer display.

Right controller:

1. Menu button: not assigned
2. Touchpad:
a. touch shows the straight pointer.
3. Trigger: uses the held item or interacts with UI element the pointer aims at.
4. Grip: picks and holds the pickable item.

Fig. 1. Architecture of the VR serious game including the dedicated controllers (© iMareCulture)

An overview of the virtual reality serious game is shown in Figure 2. When the player enters the main game in the unified environment, the first task is to search the area and find scattered amphoras and a shipwreck. The search and discovery game assessed two maritime archaeological methods for search and discovering artefacts including circular and compass search. Evaluation results with 30 participants showed that the circular search method is the most preferred and was implemented in VR (Liarokapis et al., 2020). Amphora is found when the user aims at it with the straight pointer and presses the trigger button and thus tags the amphora. Amphoras are also connected to a short video which starts playing above the left hand and it unlocks in the mother base scene in the central panel. The user can either watch the video or interact with the UI element to skip it. Around the area are also scattered objects other than amphoras, which can also be tagged, but no video is played since these objects are not important. When the player finds all amphoras or wants to move to the next task (photogrammetry).

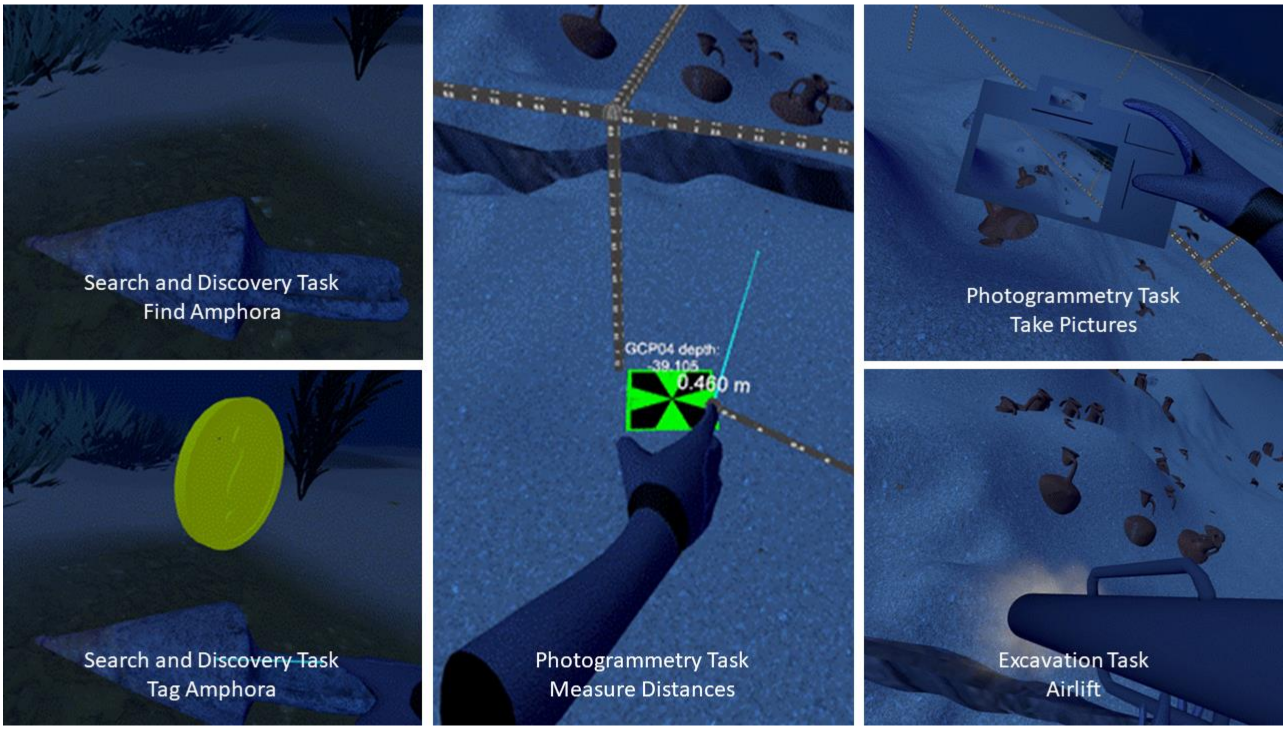


Fig. 2. Overview of the three tasks in the VR serious game (© iMareCulture)

The purpose of the photogrammetry task is to document an underwater site (Doležal et al., 2019). It consists of taking photos in VR that will be used for post-processing photogrammetry analysis. At the start of activity, user places around 4 ground control points (GCP) markers in the site by pressing the left trigger button. Then they need to measure distances between all the markers by pressing and holding the right touchpad. When the measurements are completed, the user must pick up the digital camera and systematically cover the whole area of interest with photos. It is recommended to use swim locomotion mode instead of teleportation. For the photo to be valid in photogrammetry processing, it needs to overlap at least by 30 % with another photo. There are two ways of taking photos. First, the spiral method – the user takes photos from the center in the spiral. The second method, which is recommended in this scenario, is by taking photos in lines perpendicular to the ground. The task is finished after taking at least hundreds of photos. Though taking more photos will provide more accurate result, but it will take more time to process the scan. All photos are stored in the installation folder and can be later used to calculate the 3D scan in any photogrammetry software.

The final activity is the shipwreck excavation (Bruno et al., 2017; Kouřil and Liarokapis, 2018). User can experience the process of underwater excavation by removing sand from the seabed. Similarly, to the previous task, user must grab the airlift device and they can use the device to slowly dredge sand from the seabed and look for objects buried in sand. The player should uncover as much of the shipwreck as possible. Two different approaches were implemented. The first one was based on realistic sand simulation and although it provided a more accurate simulation, it was not effective for large areas (Kouřil and Liarokapis, 2018). The second method, which was preferred and used in the final version was not so computationally expensive and provided reasonable simulation results (Bruno et al., 2017).

AR Guide

The Augmented Reality (AR) within the underwater navigation is intended to enable the diver a new and more immersive experience compared to a classic recreational dive. The site used is the underwater Archaeological Park of Baiae which is located off the north-western coasts of the bay of Puteoli in Naples. The AR allows the diver to view the hypothetical reconstruction of the structures and artifacts that are superimposed on the present status of the underwater archaeological site. The diver-visitor is equipped with an AR enabled underwater smartphone which estimates the diver's position and orientation. To enhance the underwater experience of diver visitors, a hybrid AR application was developed. An overview of the architecture of the system is presented in Figure 3.

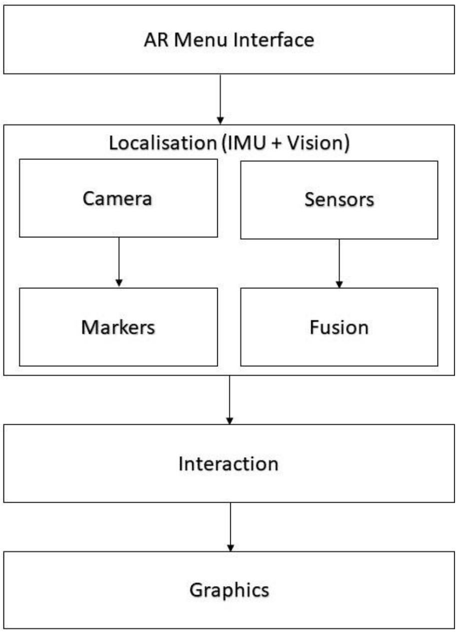


Fig. 3. Architecture of the AR guide (© iMareCulture)

Vision underwater is degraded by several factors such as absorption of light and turbidity, which creates a problem for vision. It is also problematic in terms of localization when computer vision is employed for localisation. To enhance the quality of underwater images, a real-time dehazing algorithm was proposed and implemented (Čejka et al., 2018; Čejka et al., 2019). To further improve accuracy and increase the robustness, data coming from inertial sensors located in the device are used. The AR application records the data from the camera and sensors, detects markers, computes the position of the camera, and renders the virtual model at the proper position. Additionally, it presents interesting information about the site, and records the data from the camera and sensors for further optimization of the application.

Fig. 4. Underwater AR mobile phone with housing (© iMareCulture)

The system is implemented and tested on a Samsung S8 smartphone and a Diveshot housing (Fig. 4). It also contains five optical buttons that divers press by covering the corresponding sensor with a finger and sends the click events to the smartphone using Bluetooth, behaving like an external Bluetooth keyboard. The user interface of the application is designed to use only with the five buttons of the housing because the housing prevents divers from controlling the smartphone directly by touching its surface. It was optimized for smartphones, because their screen is much smaller than the screen of tablets and require less controls so as not to overload the user. It is divided into two parts, a left part dedicated for the application and a right part containing a visual representation of the buttons of the housing. The function and labels of the buttons change according to the needs of the application. Additionally, the screen contains a small clock in the upper left corner.


15:43:20

Step 1/3
Welcome to Villa con ingresso a protiro. Go around the room with mosaic and enjoy the virtual model. See especially the frescos on the walls.
Press Next to continue.

Memory:
RAM: 6%
Internal: 0%
External: 14%

Fig. 5. AR view of "Villa con ingresso a protiro" (© iMareCulture)

The application provides a 3D hypothetical reconstruction of "Villa con ingresso a protiro" which is located at approximately 6 meters' depth. The user interface is shown in Figure 5. Most of its screen is taken by the AR view, which maintains 16:9 aspect ratio of the camera. The right part with buttons automatically shrinks to fit the missing space of the screen. The clock and the information text about the site are displayed over the AR view. The status of saving camera and sensors streams is depicted in lower right corner.

User experience was evaluated with 10 professional divers and the complete results were recently published (Čejka et al., 2021). Divers reported that they expect that the system will be used in practice for touristic purposes soon. They could see the virtual scene very clearly and agreed that they felt completely immersed in the virtual environment and stopped paying attention to their surroundings. Some divers complained that due to their complete immersion, they lost the feeling of actual diving, which was substituted by their impression of the virtual experience.

Conclusions

This paper has presented two different applications for maritime archaeology. The first application was implemented in immersive VR and aimed in educating the public about the process teaching maritime and archaeologist students the main principles of 'site formation', 'surveying' and 'excavation'. Although the final version of the VR application was not evaluated, the individual components were evaluated prior to the integration. The second application is an underwater AR touristic guide for divers. This application was formally evaluated, and results showed that it was very successful as an underwater touristic guide. In the future, results from both applications will be used to design and implement new underwater applications for maritime archaeology.

Acknowledgements

This research is part of the i-MareCulture project (Advanced VR, iMmersive Serious Games and Augmented REality as Tools to Raise Awareness and Access to European Underwater CULTURal heritagE, Digital Heritage) that has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 727153. This research was also partially supported by the project that has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 739578 (RISE—Call: H2020-WIDESPREAD-01-2016-2017-TeamingPhase2) and the Government of the Republic of Cyprus through the Directorate General for European Programmes, Coordination and Development.

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Session:
AI methods for digital humanities

New pathways towards Cultural Heritage

Piotr KUROCZYNSKI | Günther GÖRZ | Christoph SCHLIEDER

Call

Piotr KUROCZYNSKI, Hochschule Mainz – University of Applied Sciences, Germany
Günther GÖRZ, FAU Erlangen-Nürnberg, Germany
Christoph SCHLIEDER, Otto-Friedrich-Universität Bamberg, Germany

Keywords: *Knowledge Representation—Natural Language Processing—Image and Object Analysis—Reasoning*

The digital transition opens new perspectives for researchers interested in cultural processes. An increasing part of the material and immaterial heritage of Western culture is accessible via digital representations such as digital editions of manuscripts, multispectral images of paintings, 3D models of archaeological findings or 3D models of source-based reconstructions. Digital representations have the obvious advantage of permitting simultaneous remote access.

Additional effort is needed to include more cultural creations in the digital transition. Beyond that, the sheer number of those creations already digitally accessible raises new challenges for humanities scholars. The task of analyzing and linking the many pieces of information becomes more important and difficult than ever.

AI methods provide solutions to some of the challenges involved. The Semantic Web technology stack, for instance, permits knowledge-based algorithms to assist scholars in the task of linking large cultural data sets. Another issue is the vagueness and uncertainty omnipresent in the historic study of cultural processes. AI research has devised a number of methods able to deal with these phenomena. It is important, however, to realize that humanities scholars have specific requirements.

The session gathers AI researchers and interested digital and spatial humanities scholars. We encourage submissions that report on work in progress or present a synthesis of emerging research trends. Topics of interest include, but are not limited to:

- Knowledge representation for source-based (hypothetical) 3D reconstructions
- Web-based image and object classification and analysis
- Ontological approaches to semantic heterogeneity
- Knowledge graphs in the humanities
- Spatio-temporal reasoning for archeology, built heritage (art and architecture)
- Reasoning about and learning from uncertain or ambiguous evidence
- Serious game design for cultural heritage, crowdsourcing and location-based games

Digital Analysis of Historic Bridge Images

F. Michael BARTLETT, Professor Emeritus, Dept. of Civil & Environmental Engineering, Western University, Canada
William J. TURKEL, Professor, Department of History, Western University, Canada.

Abstract: This short paper summarizes work-in-progress to create a database of 4800 electronic images of historic American and Canadian highway, railway and pedestrian bridges constructed between 1865 and 2019. The images were retrieved from Wikipedia, Wikimedia Commons, and the Historic American Engineering Record (HAER) websites. Machine-vision systems and image-processing techniques are applied to determine whether a bridge is present in the image, the form or type of bridge, the date of construction and other features. The Artificial Intelligence classification identifier was 85–92% accurate when distinguishing between girder and through-truss bridge types and roughly 70% accurate when distinguishing between cantilever, through-arch, girder, through-truss and deck arch bridges types. It is perhaps more challenging to determine the date of construction because time is a continuum. The temporal evolution of bridge types and construction details is somewhat blurry and varies between different geographic regions. Some configurations, such as covered bridges and Pratt Truss bridges, haven't evolved significantly for quite some time. A possible next step will be to use image-processing and photogrammetric techniques to try to identify the vantage point from which the bridge was photographed. The relevance of this study extends beyond those interested in historic bridges to scholars studying image classification in other areas of the digital humanities.

Keywords: *Artificial Intelligence—Automatic Identification Systems—Highway Bridges—Historic Images—Machine Learning*

CHNT Reference: Bartlett, F. M. and Turkel, W. J., 2020. Digital Analysis of Historic Bridge Images, in Börner, W., Rohland, H., Kral-Börner, C. and Karner, L. (eds.) *Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020.* Heidelberg: Propylaeum.
doi:10.11588/propylaeum.1045.c14475

Introduction

This short paper summarizes work-in-progress to create a database of electronic images of historic bridges. These images are being used concurrently to develop machine-vision systems and image-processing techniques to automatically identify, in historical and contemporary images of cityscapes and landscapes: (1) the presence of a bridge or bridge component in an image; (2) the form (or type) of bridge or bridge component; (3) the age and other features; and (4) the vantage point from which the bridge was photographed.

Database of Historic Bridge Images

A database of 4800 images of Canadian and American highway, railway and pedestrian bridges constructed between 1865 and 2019 has been created and continues to be extended. The images were retrieved from Wikipedia, Wikimedia Commons, and the Historic American Engineering Record

(HAER) websites. Many American bridges are listed on the U.S. Department of the Interior's National Register of Historic Places, although those less than 50 years old are ineligible for this recognition.

Each bridge is assigned a unique identifier and is associated with the fields shown in Table 1. The Wikidata identifier links records in the bridge table with open data. A sample record (for the Lions' Gate Bridge in Vancouver, BC) is available at https://www.wikidata.org/wiki/Q124352. Among other things, it contains the designer, the date the bridge was officially opened, the longest span, heritage designation, identifiers for other databases and translations of the bridge's name into other languages.

Table 1: Fields to Define Bridges

Field	**Contents**
Name of Bridge	Text
Bridge ID (primary key)	Number
Wikidata ID	Concept URI (to link record to open data)
Location	City/Town/County, State (Province), Country
Date of Construction	Year
GPS Location	Latitude, Longitude
Main Span Type	Main Span Type ID (foreign key to Table 2)
Approach Span Type	Deck arch, Deck truss, Girder, Half-through arch, Half-through truss, Through arch, Through truss or NULL

Each bridge is characterized by a Main Span Type, shown in Table 2. Most of the Main Span Type Classifications include Subclassification options. Each combination of Classification and Subclassification is assigned a unique Main Span Type ID number. For example, Figure 1 shows Eagle Point Bridge in Dubuque, Iowa. The main spans are in the background, to the right are steel through trusses – the roadway goes through the trusses. The approach spans, in the left foreground, are steel Pratt deck trusses – the trusses are entirely underneath the roadway.

Table 2: Main Span Type Classifications

Classification	**Subclassification**
Cable-stayed	Concrete, steel
Cantilever	Warren or NULL
Covered	Burr arch, Howe, Lattice or NULL
Deck arch	Concrete, Concrete open spandrel, Steel, Stone
Deck truss	Bascule, Camelback, Howe, Lift, Parker, Pratt, Swing, Warren
Girder	Bascule, Concrete, Lift, Steel, Swing
Half-through arch	Concrete, Concrete open spandrel, Steel, Stone
Half-through truss	Bascule, Camelback, Howe, Lift, Parker, Pratt, Swing, Warren
Suspension	NULL
Through arch	Concrete, Concrete open spandrel, Steel
Through truss	Bascule, Camelback, Howe, Lift, Parker, Pennsylvania, Pratt, Swing, Warren

Fig. 1. Eagle Point Bridge, Dubuque IA, 1902 (HAER IA-2-56). (Image Source: https://www.loc.gov/resource/hhh.ia0114.photos/?sp=56&q=Eagle+Point+Bridge)

Each image is assigned a unique identifier and associated with the fields shown in Table 3. Each bridge is typically associated with more than one image. Rare images depict two or more distinct bridges.

Table 3: Fields to Define Images

Field	**Contents**
Photo ID (primary key)	Number
Bridge	Bridge ID (foreign key to Table 1)
Image Restriction	Public Domain or Restricted
Source URL	Wikipedia, Wikimedia Commons., or HAER

Computational Analysis

The compilation of the image database is accompanied by development of an automated system for analysing historical and contemporary images of bridges, depicted in Figure 2 and based on similar systems previously developed[1] for use by historians of technology.

'Ground truth' images that have been analysed by Bartlett are retrieved from the image database to use for testing and training. Test images can also be retrieved from other sources, typically collections built by web crawling. Creating a custom neural net that segments an image of a natural scene to identify general structures of interest requires a large collection of labelled image data that we do not possess. Instead, images are passed through an Ademxapp Model A1 neural net[2] that was pre-trained with the ADE20K database of more than 20000 images[3] to segment scenes into semantic classes. A number of alternatives could have been applied at this stage, but this model does an excellent job and was readily available in pretrained form. Figure 3 shows a sample output where the system has quite accurately identified the Pierre Laporte suspension bridge in the foreground and the Pont de Quebec cantilever truss in the background. In a preliminary trial involving 100 images, the Ademxapp Model A1 correctly identified bridge elements in 83 of 84 images that contained bridges and correctly identified that no bridge elements were present in all 16 images that did not contain bridges.

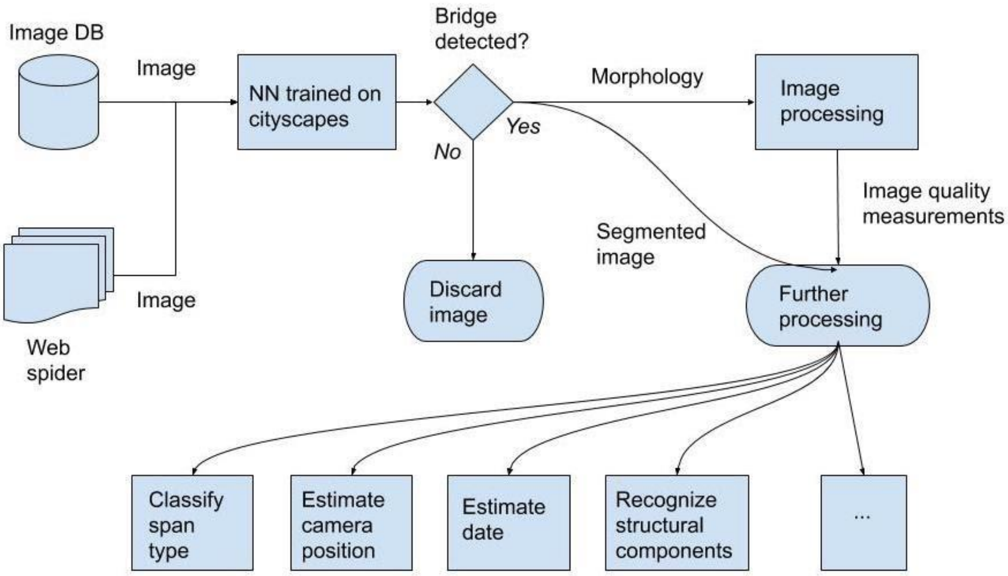


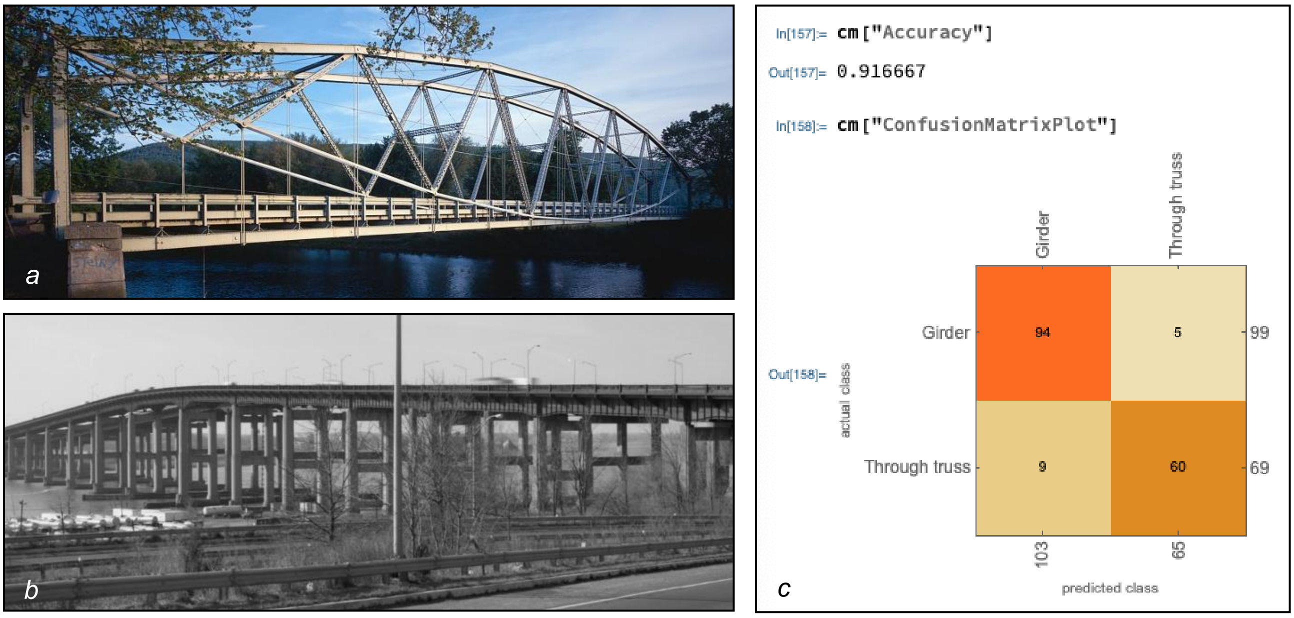
Fig. 2. Block diagram of an automated system for analyzing bridge images. (© W.J. Turkelt)

a b

Fig. 3. Machine vision identification of bridge and other features a) original image; b) identified features. (Image source: a) https://commons.wikimedia.org/wiki/File:LaPorte_de_Quebec_(5802230245).jpg, b) Created by W. J. Turkel using Ademxapp Model A1

If no bridge is detected in the input image, the image is discarded, and the system retrieves another. If a bridge has been detected, morphological information from the image is passed to an image processing module to assess the quality of the image for the purposes of further automated handling. The shape of the segment of the image that contains the bridge is measured to assess its orientation, how much of the whole image it comprises, and so on. These measures are used to determine what kinds of further automated processing are possible or appropriate.

Other machine learners (such as logistic regression models) have been trained to categorize bridge images by main span type, typically achieving accuracies upwards of 85%. For example, Figure 4 shows an example of using the artificial intelligence classifier to determine the main span type. The AI was trained using 80 images of through truss bridges, such as the elegant 1889 Lenticular through truss at Lycoming County, Pennsylvania, and 80 images of girder bridges, such as the 1940 Edison Bridge in New Jersey. Then it classified 168 new images as either girder bridges or through truss bridges. The screen shot indicates that the classification was almost 92% accurate as confirmed by the Confusion Matrix plot.

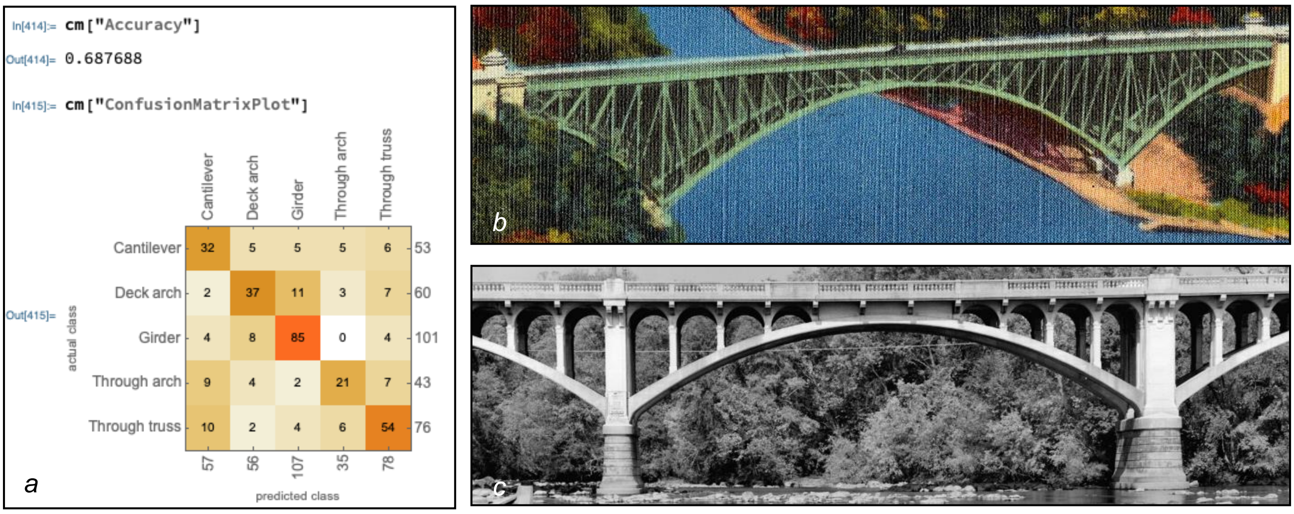


```
In[157]:= cm["Accuracy"]
Out[157]= 0.916667
In[158]:= cm["ConfusionMatrixPlot"]
Out[158]=
```

	Girder	Through truss	
Girder	94	5	99
Through truss	9	60	69
	103	65	

Fig. 4. AI classifier to determine bridge type: a) Lenticular Through Truss, Lycoming Co. PA, 1889 (HAER); b) Edison Bridge, Sayreville NJ, 1940 (HAER); c) screen shot of Mathematica Confusion Matrix and accuracy. (Image sources: a) https://www.loc.gov/pictures/item/pa3981.color.218398c/resource/ b) https://www.loc.gov/pictures/item/nj1641.photos.347596p/ c) Created by W. J. Turkel using Mathematica.)

Figure 5 shows an example where the classification was extended to consider five different types, including cantilever, deck arch, girder, through arch and through truss bridges. In this case, the accuracy was not so good, roughly 69%. Looking more closely at the confusion matrix there were no girder bridges that were erroneously classified as through arches, which is not surprising as they are markedly different forms. There were, however, cantilevers erroneously classified as deck arches and deck arches erroneously classified as cantilevers. In this case, one might have some sympathy for the computer! Compare, for example, the 1932 French King Bridge in Gill, Massachusetts, a steel cantilever bridge, with the 1928 Gervais Creek Bridge in South Carolina, a deck arch bridge. The cantilever has diagonal members in the trusses and the deck truss has thick vertical members over the piers – but otherwise, their appearances are not particularly different.



```
In[414]:= cm["Accuracy"]
Out[414]= 0.687688
In[415]:= cm["ConfusionMatrixPlot"]
Out[415]=
```

	Cantilever	Deck arch	Girder	Through arch	Through truss	
Cantilever	32	5	5	5	6	53
Deck arch	2	37	11	3	7	60
Girder	4	8	85	0	4	101
Through arch	9	4	2	21	7	43
Through truss	10	2	4	6	54	76
	57	56	107	35	78	

Fig. 5. AI classifier to determine multiple bridge types: a) screen shot of Mathematica Confusion Matrix and accuracy; b) French King Bridge, Gill MA, 1932 (Commons.wikimedia.org); c) Gervais Creek Bridge, Columbia SC, 1928 (HAER) (Image Source: a) Created by W. J. Turkel using Mathematica b) https://www.digitalcommonwealth.org/search/commonwealth:6d5701630 c) https://www.loc.gov/pictures/item/sc0757.photos.150689p/)

Future work will focus on developing machine learners for a variety of automated tasks. One example is the automated recognition of structural components like truss type. Figure 6 shows Pratt (horizontal top chord), Parker (polygonal top chord) and Camelback (5-element top chord) trusses.

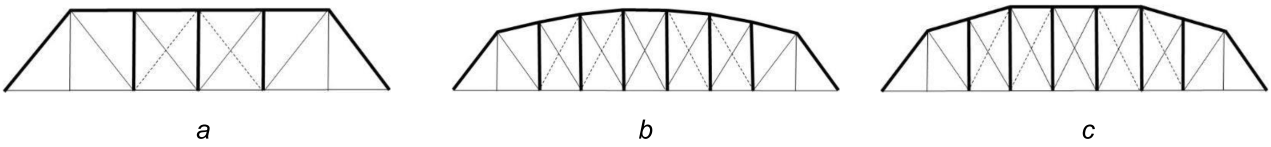


Fig. 6. Truss configurations a) Pratt; b) Parker; c) Camelback. (HAER) (Created by F. M. Bartlett)

Another example is estimating the date of bridge construction. 'Black-box' machine learners perform this task using features that are usually not legible to humans. Human experts, on the other hand, use a variety of construction details, including the examples shown in Table 4. Developing the database in conjunction with an automated system for analysing bridge images allows researchers to explore the degree to which the system should be trained to explicitly recognize construction details (like the use of pin-connected or riveted trusses). This is challenging, however, time is a continuum, so the classification must consider the shades of grey between black and white.

Table 4: Evolution of Bridge Construction Details.

Date	**Feature**
~1875	Emergence of double-intersection trusses
~1880	Transition from empirical to theoretical bridge design completed in US4
~1890	Emergence of steel construction instead of wrought/cast iron construction
~1900	Emergence of plain and reinforced concrete (piers, abutments, superstructure)
~1910	Milan theory of earth-anchored suspension bridges causes markedly more slender stiffening elements.
~1910	Emergence of concrete tied arch ("rainbow") bridges and concrete open spandrel deck arch bridges
~1920	Emergence of riveted trusses instead of pin-connected trusses
~1930	Emergence of rigid frame construction
~1950	Emergence of prestressed concrete construction
~1950	Transition from built-up steel members to single rolled shapes
~1980	Emergence of cable-stayed bridges instead of cantilever trusses

Moreover, some types have not evolved much. The 377 images of wooden covered bridges in the database suggest that their form and construction details have often not changed appreciably for over a century. People are nostalgic about the traditional forms. Similarly, the optimization of steel Pratt trusses was essentially completed more than a century ago, so while construction details change, the general proportions and member massing do not. Another challenge is that technological progress varies across geographical regions, and progress for different bridge types typically varies differently across different geographical regions.

Some transitions are more difficult to date, for example

- The transitions from pin-connected to riveted to shop-riveted/field-bolted to shop-welded/field bolted to welded steel construction. For example, Figure 7a shows the 1891 Harvard Bridge across the Charles River in Boston. The variable-depth steel plate girders are built up using rivets. When the bridge was replaced in the 1980s with similar variable-depth plate girders, the construction is welded, not riveted.

a b

Fig. 7. Harvard Bridge plate girders a) Riveted construction, 1891 (Source: HAER); b) Welded construction, 1980s (Image source a) https://www.loc.gov/pictures/item/ma1293.photos.076534p/resource/ b) Denimadept, CC BY-SA 3.0 https://creativecommons.org/licenses/by-sa/3.0, via Wikimedia Commons)

- The transition to more slender, and so more graceful, elements and structures due to stronger and stiffer materials.
- The transition to more complex geometries and structural systems due to enhanced computational capabilities. This is particularly evident in the design of cable-stayed bridges. Figure 8a shows the 1973 John O'Carroll Bridge in Sitka, AL, one of the first cable-stayed bridges constructed in the United States. There are a total of eight cables in the two vertical planes. It is statically indeterminate to the 4th degree – that means that four equations of deflection compatibility must be added to the equations of equilibrium to analyse the structure. In contrast, Figure 8b shows the 2012 Margaret Hunt Hill Bridge in Dallas, TX, designed by Santiago Calatrava. It has a much more complex geometry, with 58 cables arranged in surfaces that resemble hyperbolic paraboloids, and the degree of indeterminacy is beyond simple calculation. Powerful 3-Dimensional structural analysis programs are necessary to demonstrate that this structure can successfully resist the loads that it carries.

a b

Fig. 8. Evolution of cable-stayed bridges a) John O'Connell Bridge, Sitka AK, 1973 (Source: Wikipedia); b) Margaret Hunt Hill Bridge, Dallas TX, 2012 (Image source a) https://commons.wikimedia.org/wiki/File:John_O%27Connell_Bridge,_Sitka_2013.JPG b) Michael Barera, CC BY-SA 4.0 https://creativecommons.org/licenses/by-sa/4.0, via Wikimedia Commons)

- The impact of the increased labour costs: fewer built-up steel members, more precast concrete construction and the use of concrete instead of masonry in towers, piers and foundations.

A final example of a task that is currently being automated is to use image processing and photogrammetric techniques to try to identify the vantage point from which the bridge was photographed. Others[5] identified five specific vantage points that are important for viewing bridges, “(a) travelling over the bridge at slow speed; (b) travelling over the bridge at high speed; (c) travelling under the bridge at slow speed (d); travelling under the bridge at high speed; and (e) viewing the bridge from a distance.” Successfully estimating camera position with respect to the bridge will be useful for more sophisticated image understanding tasks.

Summary

This short paper has summarized work-in-progress to create a database of 4800 electronic images of historic American and Canadian highway, railway and pedestrian bridges constructed between 1865 and 2019, retrieved from Wikipedia, Wikimedia Commons, and the Historic American Engineering Record (HAER) websites. These images are being used concurrently to develop machine-vision systems and image-processing techniques to automatically identify, in historical and contemporary images of cityscapes and landscapes: (1) the presence of a bridge or bridge component in an image; (2) the form (or type) of bridge or bridge component; (3) the age and other features; and (4) the vantage point from which the bridge was photographed. The Artificial Intelligence classification identifier was 85–92% accurate when distinguishing between girder and through-truss bridge types and roughly 70% accurate when distinguishing between cantilever, through-arch, girder, through-truss and deck arch bridges types. It is perhaps more challenging to determine the date of construction because time is a continuum: the evolution of bridge types and construction details is somewhat blurry and varies between different geographic regions. A possible next step will be to use image-processing and photogrammetric techniques to try to identify the vantage point from which the bridge was photographed. The relevance of this study extends beyond those interested in historic bridges to scholars studying image classification in other areas of the digital humanities.

Funding

The authors declared no external funding of the presented work.

Conflict of Interests Disclosure

The authors declared no conflicts of interest.

Author Contributions

Conceptualization: F. M. Bartlett and W. J. Turkel
Data curation: F. M. Bartlett
Formal Analysis: W. J. Turkel
Investigation: F. M. Bartlett
Methodology: W. J. Turkel

Project Administration: F. M. Bartlett and W. J. Turkel
Resources: W. J. Turkel
Software: W. J. Turkel
Visualization: F. M. Bartlett and W. J. Turkel
Writing – original draft: F. M. Bartlett and W. J. Turkel
Writing – review & editing: W. J. Turkel and F. M. Bartlett

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Jones-Imhotep, E., and Turkel, W. J. (2019). ‘The Analog Archive: Image-Mining the History of Electronics’, in Kevin Kee and Timothy Compeau *(eds.) Seeing the Past with Computers: Experiments with Augmented Reality and Computer Vision for History*. Ann Arbor: University of Michigan Press.

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Preparing the past for the future

Curating a daylight simulation model of Hagia Sophia for modern data infrastructures

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Lars Oliver GROBE, Lucerne University of Applied Sciences and Arts, Switzerland

Abstract: Digital humanities and artificial intelligence applications rely on structured sets of data and metadata. Larger and more complex dataset as a product of growing computing power and widely available advanced tooling demand modern data-management within projects, while scientific transparency, reusability, and interoperability demand machine-readable publishing and linking of project data. The latter implies infrastructure for long-term storage and AI-assisted search. Emerging platforms as the National Research Data Infrastructure (NFDI) and Specialised Information Services (FID), both sponsored by the German government provide suitable repositories but require the curation of research data. This paper examines the interdependency of in-project data-management and publishing and localizes possible AI-applications in in the context of a non-ideal case-study – the heterogeneous dataset of a light-simulation model of Hagia Sophia. It proposes a separation of the project-data into five scopes – raw data collections, reconstruction and material models, simulation environment, simulation results and digital publications – that allow to develop transferable solutions and integration into emerging infrastructures for reuse, search, linking and publishing of data between projects. The paper concludes that AI-applications in this context provide more general, transferable solutions for search and spatial image organisation within the research infrastructure and very specific solutions within a project. A standardised organisation of research data and metadata has to fit these applications.

Keywords: *Data Management—FAIR Principles—Simulation Model—FID—NFDI—AI Application*

CHNT Reference: Noback, A. and Grobe, L. O. (2020). 'Preparing the past for the future: Curating a daylight simulation model of Hagia Sophia for modern data infrastructures', in Börner, W., Rohland, H., Kral-Börner, C. and Karner, L. (eds.) *Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020.* Heidelberg: Propylaeum. doi:10.11588/propylaeum.1045.c14476

Introduction

A detailed simulation model of Hagia Sophia (Fig. 1) emerged from more than 20 years of research in its daylighting (Hauck et al., 2013; Noback et al., 2020).[1] From the start this model was meant for distributed development and sharing (Grobe et al., 2020). It seems to fit the recently available infrastructures for data publishing, but efforts to publish its heterogeneous data set reveal interesting challenges that – in the first step – demand some conceptional work. These challenges seem to be typical for the current state of digitalisation. Its resulting data-rich research environments demand

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[1] The research started as a project with the title "Die Hagia Sophia Justinians in Konstantinopel als Schauplatz weltlicher und geistlicher Inszenierung in der Spätantike", that was founded by the Deutsche Forschungsgemeinschaft (#5194526).

data management to guarantee standard conformity, transparency, long term storage, accessibility, intellectual property and security. Adequate data publishing infrastructure is a requirement for the application of computational agents including *artificial intelligence* that depend on structured and machine-readable data and meta-data. This is best summarised in the FAIR Principles (Wilkinson et al., 2016) that require that "all research objects should be *Findable, Accessible, Interoperable and Reusable* (FAIR) both for machines and for people". Internal workflows, separation of different types of data, annotation, and external referencing have to comply with this kind of research practice.

Fig. 1. A visualisation of Hagia Sophia's interior in the sixth century accounting for contrast and brightness based on daylight simulation. The simulation environment includes a reconstruction of the historic geometry and the optical properties of the surfaces. The environment is associated with a multitude of research data. © Authors.

Data publishing in the context of new research data management platforms

Multiple platforms provide opportunities for data publication, research data management, and community integration. They ask for contributions from the research community to their further development. The German government alone invests in two such major research infrastructure programs:

1. The National Research Data Infrastructure (NFDI), whose "aim is to systematically manage scientific and research data, provide long-term data storage, backup and accessibility, and network the data both nationally and internationally."[2] It provides its science-driven data services to specific *research communities* through the consortiums NFDI4culture (art history, architecture etc.), NFDI4objects (archaeology, in preparation) or NFDI4Ing (engineering).

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[2] https://www.dfg.de/en/research_funding/programmes/nfdi/

2. Through the Specialised Information Services (FID), the DFG funds[3] libraries that support scientists in specific, similar fields, e.g. arthistoricum.net[4] (art history), Propylaeum[5] (classical and ancient studies), or FID BAUdigital (building science).[6]

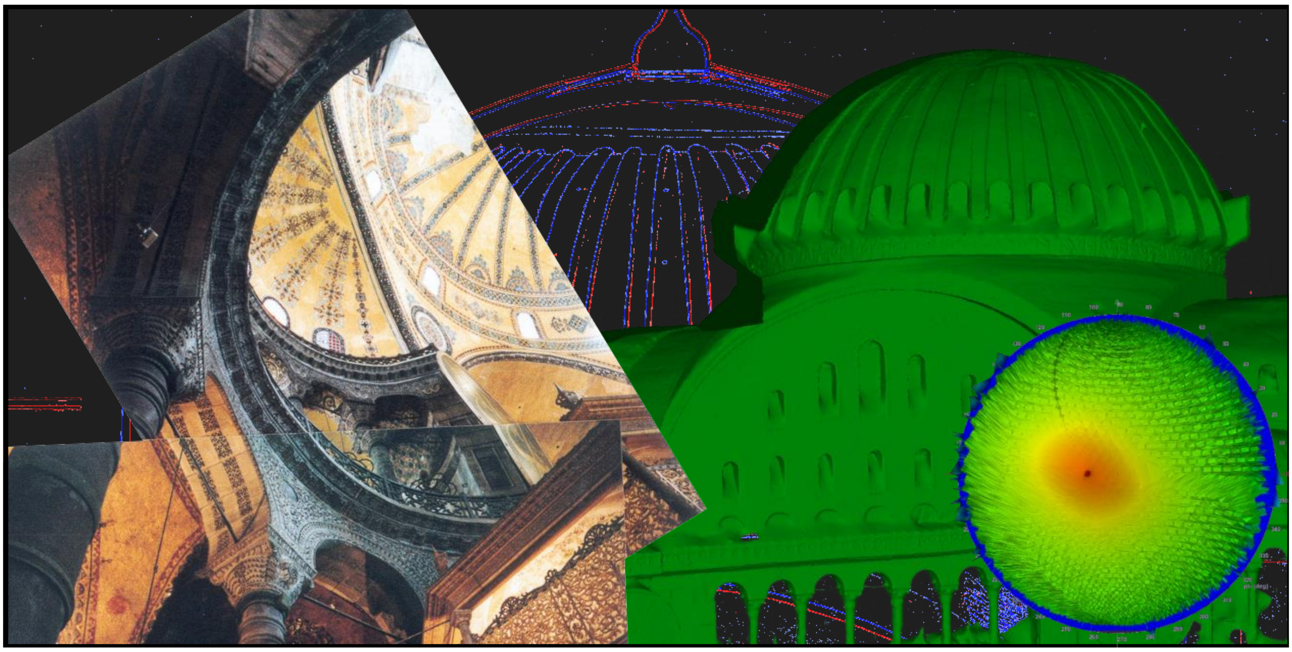

Fig. 2. Exemplary data from the Hagia Sophia project. Digital and analogue images from the photographic documentation (left). Digitised plans from a building survey (background). Triangular geometry derived from structure from motion techniques (right). Data from goniophotometric measurements (bottom right). © Authors.

The focus groups of the FID BAUdigital include research communities in the field of *built cultural heritage*. The FID is developed by the University Library Braunschweig, the University and State Library Darmstadt, the TIB – Leibniz Information Centre for Science and Technology and the Fraunhofer Information Centre for Planning and Building. It started in autumn 2020 and its current key activity is a community driven requirements analysis. The FID's goal is to provide web-services that *include AI applications*:

- Deep learning for image and video analysis, presumably based on the projects iART[7] and VIVA[8].
- Semantically enriched search with machine learning, presumably based on the project PubPharm (Wawrzinek et al., 2019).
- A Co-occurrent based recommendation system (Boubekki et al., 2017).

A case study for machine-readable data

In this context of research data management, the model of Hagia Sophia lends itself as a case to study the role of data, its citability and interoperability in cultural heritage. It allows to evaluate the internals of a dataset that presents a realistic, non-ideal case for curation. Approaches to transform

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[3] https://www.dfg.de/en/research_funding/programmes/infrastructure/lis/funding_opportunities/specialised_info_services/index.html
[4] https://www.arthistoricum.net/en/about-us/
[5] https://propylaeum.de/en/about-us/
[6] https://www.fid-bau.de
[7] https://projects.tib.eu/en/iart/about/
[8] https://projects.tib.eu/en/viva/projekt/

the model from its current state are discussed as well as insights for the development of research data infrastructures and AI applications, including:

- extending research platforms in cultural heritage to comply to FAIR principles,
- utilising research data infrastructures and contribute to their development,
- how to link research to its sources and to comparable results,
- how to reach common data management solutions,
- how to benefit from AI applications.

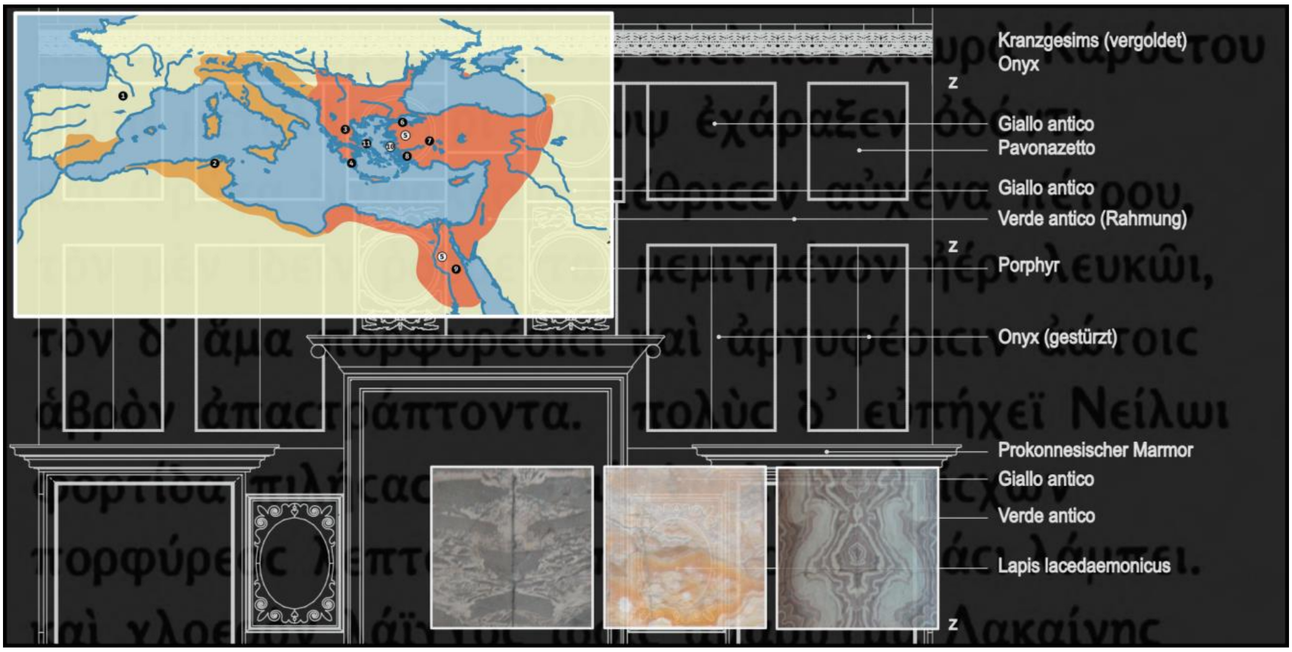


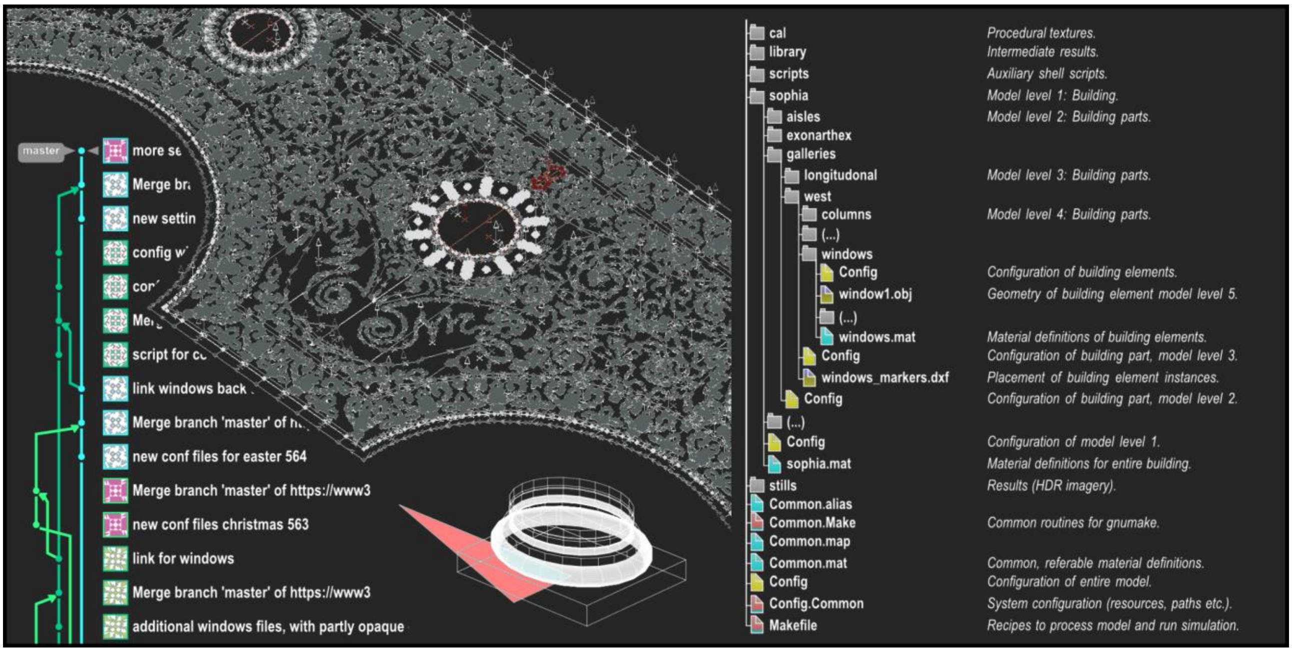
Fig. 3: External dependencies of the reconstruction model. The reconstructed marble decoration (background) describes names, colors, and origins of the materials. It is cross-referenced with present-day evidence in the building (bottom) and a marble collection related to Roman quarries. The model references these sources by page numbers of the catalogue but should rather allow open-linked data. © Authors.

The present heterogeneous dataset

The dataset is currently split into static content stored on a file server, and the version-controlled simulation environment. The former comprises a photographic documentation, digitised survey plans as well as photogrammetric data. It further includes measured optical properties, for example of Roman window glass, glass mosaic tesserae and marble samples (Fig. 2).

The reconstruction combines information from various sources to a plausible model (Fig. 3). For example, the wall decoration that fits the identified marble material from multiple imperial quarries forms a consistent geometry. The reconstruction refers to external sources, for example historic texts and objects from collections such as historic marble samples from Berlin. In this case it can only refer to pages of text (Veh, 1977) and figures in printed catalogues (Mielsch, 1985).

For the simulation environment simple, the choice of text-based triangular and polygonal mesh representations of all geometric objects has supported version control and has avoided compatibility problems over the decades. However, efficient editing of the reconstruction model required more complex entities due to the geometric constraints of the floor plan and the volumetric properties of the interior space. Therefore, editable CAD files of multiple proprietary formats were kept in parallel to the simulation model. These binary files do not support versioning and separation into the model's tree-structure. Data has been lost due to conversion between different versions of the CAD software. The proprietary formats hindered a structured documentation of the reconstruction efforts.



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more se
Merge bra
new settin
config w
con
Me
script for c
link windows back
Merge branch 'master' of h
new conf files for easter 564
Merge branch 'master' of https://www3
new conf files christmas 563
link for windows
Merge branch 'master' of https://www3
additional windows files, with partly opaque
```

```
cal                                  Procedural textures.
library                              Intermediate results.
scripts                              Auxiliary shell scripts.
sophia                               Model level 1: Building.
  aisles                             Model level 2: Building parts.
  exonarthex
  galleries
    longitudonal                     Model level 3: Building parts.
    west
      columns                        Model level 4: Building parts.
      (...)
      windows
        Config                       Configuration of building elements.
        window1.obj                  Geometry of building element model level 5.
        (...)
        windows.mat                  Material definitions of building elements.
      Config                         Configuration of building part, model level 3.
      windows_markers.dxf            Placement of building element instances.
    Config                           Configuration of building part, model level 2.
  (...)
  Config                             Configuration of model level 1.
  sophia.mat                         Material definitions for entire building.
stills                               Results (HDR imagery).
Common.alias
Common.Make                          Common routines for gnumake.
Common.map
Common.mat                           Common, referable material definitions.
Config                               Configuration of entire model.
Config.Common                        System configuration (resources, paths etc.).
Makefile                             Recipes to process model and run simulation.
```

Fig. 4. The simulation environment combines the geometry of the reconstruction model (top left) with material models and configurations in a file system tree (right, Grobe et al., 2020). All data except images are stored in clear text formats allowing version control (left). Objects are placed as instances (bottom centre). © Authors.

The core of the simulation environment forms a directory tree that reflects the building's spatial structure (Fig. 4). Its geometry is separated into objects, stored as meshes (DXF and OBJ). To assemble the model, objects are instantiated, positioned, and oriented according to triangular placeholders stored in so-called marker files. Complex objects are represented by sub-trees. Reflection and transmission properties are stored as text-based parametrisations of the improved Ward-model (Geisler-Moroder and Dür, 2010), or as data-driven light scattering models in XML files (Ward et al., 2014). Non-uniform appearance and colour are represented by calibrated image files. Routines to process the model, and to start simulations are formulated as a dependency graph interpreted by GNU make. The simulations are further guided by viewpoints and time-steps. The entire simulation environment except the imagery is stored in text-files and under version control – initially by CVS, later SVN, and now git – that tracks the history of changes, including comments and contributors, combined with fragmented observations, sources, and records of important guiding considerations in text files within the directory tree.

The simulation results in numeric data. From that visualisations, mimicking the human perception of contrast; false-colour representations of photometric quantities such as the illuminance on surfaces; and diagrams are derived for publication (Fig. 5). These results are stored on the file server for internal use and disseminated through publications and on request by other researchers.

A concept with five data scopes for data management and AI application

In face of the heterogeneous research data and its development it is evident that no single approach fits all needs without developing a very specific application – and ontology – that lacks generality and hinders access. Further examination of requirements for collaborative development, scientific transparency and documentation, machine-readable annotation, and dependencies to digital collections or external software-development lead to a separation into five data-scopes for the project data and digital publications as depicted in Figure 6: 1. Raw data collections, 2. Reconstruction and material models, 3. Simulation environment, 4. Simulation results and 5. Digital publications.

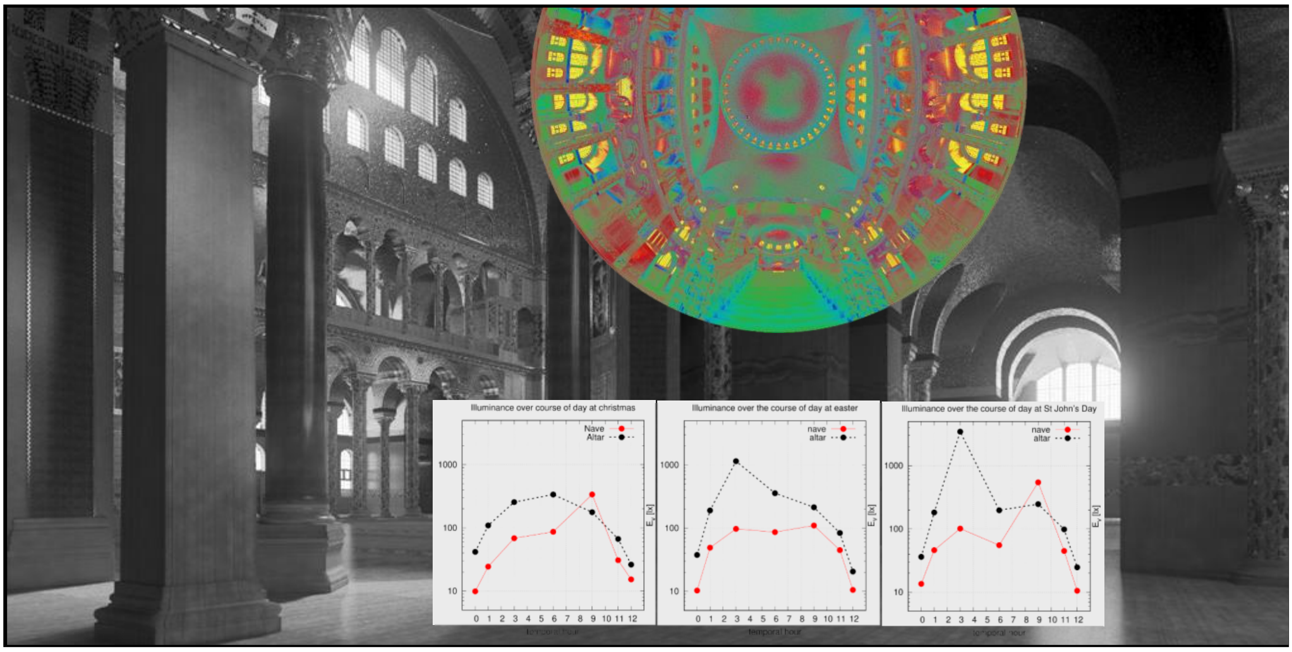

Fig. 5. Exemplary simulation results. Numeric data is stored in tabular form and visualised in diagrams (bottom) or false colour representation (top). Imagery visualises human perception models (background). © Authors.

This separation is compatible with the dataflow and dependencies within the project and is helpful for the integration into existing infrastructures or ontologies. It provides opportunities to find common solutions to similar problems in other projects and helps to define requirements for multi-purpose publication infrastructures and possible AI applications. For example, digital collections and object catalogues follow similar structures that can be reused for multiple purposes. They allow a standardised publication format as well as the application of AI assisted search tools.

References to objects in such structured data-models and suitable meta-data in all publications will enhance these possibilities and provide additional transparency. Internal and external linking between objects in the different data-scopes enables knowledge graphs as a form of scientific text, and defines anchor points for search infrastructures. For example, the photographic documentation could be ordered with AI assistance for spatial reference, search and relation to other image sources. Finally, the separation allows a step-by-step approach for the demanded publication of all research objects.

Conclusions

The proposed data scopes form horizontal layers in the diagram in which the output of a project on the right relates to the input on the left (Fig. 6). The separation presents opportunities for reuse and AI application. The latter may help with search and data mining in texts and digital collections, e.g. through word2vec (Mikolov et al., 2013), word movers' distance (Kusner et al., 2015) or a co-occurrent based recommendation system to find comparable results and publications (Boubekki et al., 2017). Another potential opportunity would be the organisation of photographic documentation for spatial reference, search and relation to other image sources. Furthermore, custom AI applications may address particular research questions, for example to solve the fitting parameters of material models or to enhance simulation and data analysis. AI applications are part of and depend on a wider complex of management and publication of research data that link individual projects in a wider community. Segmenting project data into scopes is hoped to foster a wider use of AI applications.

With the goal to enhance the ability of machines to automatically find and use data, the presented concept provides opportunities for a more general discussion about data management and exchange in similar cultural heritage projects, the application of the FAIR Principles, and the further development of collaboration platforms such as the aforementioned Specialised Information Services.

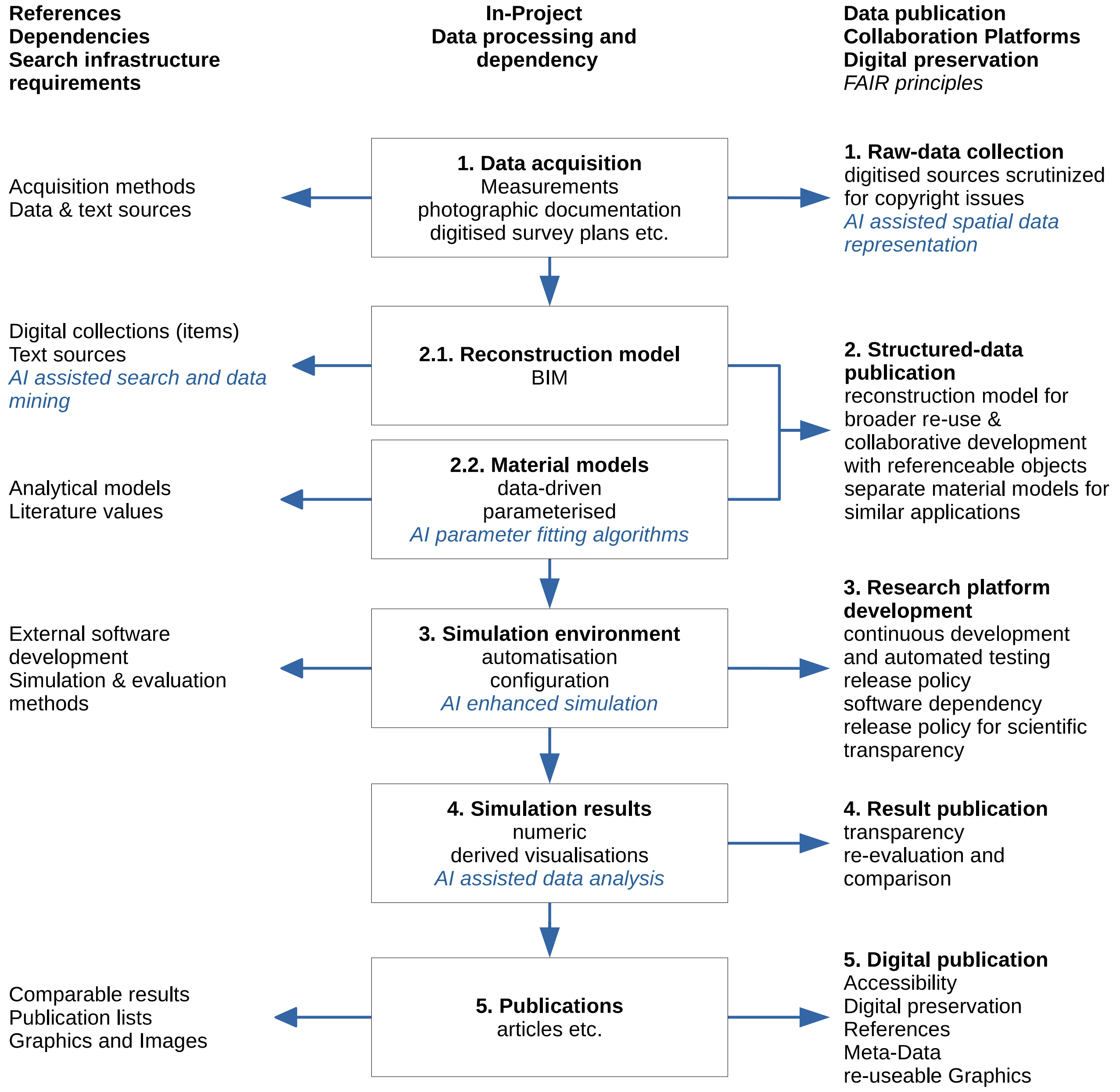

Fig. 6: Proposed five scopes for in-project data-processing, references, publication and AI applications. © Authors.

Acknowledgements

The discussed model of Hagia Sophia was developed by R. Stichel, H. Svenshon, O. Hauck, the authors, and others. It was further extended as part of the first author's Ph.D. at Technische Universität Darmstadt.

Funding

The discussed model of Hagia Sophia was developed with the support of Deutsche Forschungsgemeinschaft (DFG #5194526), the Fritz Thyssen Foundation (Az. 20.18.0.00 AA). This work on this paper is founded by the Deutsche Forschungsgemeinschaft as part of the project "FID Bauingenieurwesen, Architektur und Urbanistik digital (BAUdigital)" (#432774435).

Conflict of Interests Disclosure

The authors declare no conflict of interests.

Author Contributions

Both authors contributed equally to the paper.

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Classification of Historic Food Images

A pilot experiment on the example of the ChIA project

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Abstract: This paper describes two image classification tasks, carried out in the context of the interdisciplinary Digital Humanities project ChIA (Accessing and Analysing Cultural Image with New Technologies). On a set of selected still life food images from the Europeana collection, two classification rounds were carried out by five human annotators. On the one hand, concrete food objects were annotated; on the other hand, also abstract cultural features. The degree of precision in the description of labels was varied. In the first annotation round, no description of labels was provided and annotators relied solely on their interpretation or intuition. In the second annotation round, annotators were given concrete definitions of the labels. Besides, the annotators varied in age, gender and cultural background. The aim of these tasks was to determine whether patterns in the classified data would emerge and if so, which parameters would be decisive. As part of the evaluation the inter-annotator agreement was calculated. Preliminary results suggest that the identification of cultural features in images is highly subjective. Agreements were higher for the classification of concrete objects than for abstract features. Some tentative patterns emerged with regard to gender, but a larger annotated data set is needed to draw further and more definite conclusions.

Keywords: *Historic Food Images—Image Classification—CNN—Digital Humanities—Image Annotation*

CHNT Reference: Dorn, A., Rocha Souza, R., Koch, G., Methuku, J., and Abgaz Y. (2022). 'Classification of Historic Food Images – a pilot experiment on the example of the ChIA project', in Börner, W., Rohland, H., Kral-Börner, C. and Karner, L. (eds.) *Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020*. Heidelberg: Propylaeum.
doi:10.11588/propylaeum.1045.c14477

Introduction

This paper is realised in the context of the interdisciplinary Digital Humanities (DH) project ChIA – accessing and analysing cultural images with new technologies (https://chia.acdh.oeaw.ac.at/) (Abgaz, Dorn, Koch, and Preza Diaz, 2020; Dorn, Abgaz, Koch, and Preza Diaz, 2020). The project brings together expertise from Digital Humanities, the Cultural Heritage Sector and Computer Science. It generally aims at testing different Semantic technologies and Artificial Intelligence (AI) tools on a selected set of Europeana (https://www.europeana.eu/de) food images for improving access and analysis possibilities of knowledge contained within images for research and education purposes. This paper reports a pilot experiment on the human classification of historic food images for the purpose of creating a training data set. In particular, the classification process of a selected set of Europeana historic food images is described, taking into account also cultural aspects. This specific combination of concrete (food) and abstract (cultural) features contained within the images poses a significant challenge for both humans and machines when it comes to image classification.

In this study, the aim was to determine whether certain patterns in the classified data emerge that could potentially correspond to specific image features (depicted objects, colour, etc.) or that are particular to human annotators (cultural background, gender, age, etc.). Here the authors report on the research process and provide insights into results as well as on challenges faced.

Background – Food, Culture and Art

The kind of food consumed by humans, the way it is produced, and the cultural features associated with it – these facets are all closely related to our political and economic history as food consumption evolves parallel to different major historic and cultural eras (Hirschfelder, 2001; Ott, 2017).

Images related to food, food production or consumption, typically carry strong cultural aspects, and can be found in archaeological representations, various art forms as well as in contemporary social media (Twiss, 2019). Throughout history, food related items have been captured in different social situations and art forms. A large number of paintings and pictures stored in museums, libraries and galleries depict food items carrying strong cultural symbolism, but the cultural meaning often remains hidden to the contemporary observer (Moon, 2015). Still life paintings and images (see Fig. 1) are a particularly prominent category, in which the depiction of food, its interpretation and symbolism has played a major role throughout the centuries (Bedaux, 1987; Piepmeier, 2018). Searching for such images with cultural connotations is frequently hampered by the fact that a detailed description of all items on a picture is missing, also from the title or metadata. That's why creating structured access to implicitly and explicitly contained knowledge can create significantly more opportunities for analysing possibilities across different scholarly fields.

The Experiment – Historic Food Image Classification

As a first step in the experiment, a specific dataset and vocabulary had to be selected, as a benchmark data containing images and their relevant semantic annotations were required in order to apply AI and CNN (Convolutional Neural Network) technologies for image recognition (cf. Ciocca et al., 2018). For ChIA, this data is provided by the European portal for cultural heritage, the Europeana Collections portal (http://www.europeana.eu) with more than 32 million images available under different licenses. For image collection and retrieval, the ChIA infrastructure hosts a service that supports the collection of test datasets according to predefined search criteria and provides the unique possibility to create selected test sets for further analysis with CV/CNN/AI tools out of the wealth of (open access) Europeana digital content.

Fig. 1. Example of a still life painting with fruit. Source: “Stilleven met artisjok, fruit op porseleinen schalen, een zoutvat en een pepervat”, Osias Beert, ca. 1605 – ca. 1615, Rijksmuseum, Netherlands. Image: CC-BY-PD.

A concise set of cultural food images was carefully chosen, given the large and heterogeneous field of food images. For the purpose of this study, images on the topic of still life and fruits were selected through a targeted search on the ChIA/Europeana interface, yielding a set of a total of 392 images, including black and white, and colour paintings and drawings. The subject of still life images depicting fruit was chosen, since, on the one hand, still life images have been a popular subject of research across different disciplines and are rich in cultural symbolism. On the other hand, it also allowed us to create a more defined data set from among the vast amount of images depicting fruits in very different ways in the Europeana collection.

Next, the vocabulary for tagging was defined. Different approaches were considered based on the evaluation of frequently used concepts within the cultural images domain and iconographic descriptions, which also included the retrieval of a baseline of food concepts from the Getty Arts and Architecture Thesaurus (https://www.getty.edu/research/tools/vocabularies/aat/), the IconClass multilingual classification system for cultural content (http://www.iconclass.org/) and the FoodOn ontology (https://foodon.org/). As none of these common approaches yielded satisfactory solutions for our purpose, a different and simpler binary classification approach was chosen, taking a concrete object-related feature and one more abstract, cultural feature.

Images were tagged for food items (fruit/non-fruit) —a common task based on the presence or absence of some object; and on a cultural feature (formal/informal), which is based on personal views, cultural background, and tastes. The tagging was carried out using the MakeSense.AI application (https://www.makesense.ai/). Images were tagged by five independent annotators, in two rounds. Both tasks involved tagging the set of 392 images, for the two binary label choices (fruits/non-fruits and formal/informal). In the first round, the task was presented without detailed definitions on the classes and in the second one, more specific and concrete definitions were provided to the annotators. The five annotators came from culturally diverse backgrounds, pertained to different age groups and were of mixed gender (2 female, 3 male).

The evaluation was made using Cohen's kappa (κ), which is a common statistic to measure the inter-annotator agreement. The kappa function computes a score that expresses the level of agreement between two annotators on a classification problem. It is defined as:

$$K = (p_0 - p_e)/(1 - p_e)$$

where p_0 is the empirical probability of agreement on the label assigned to any sample (the observed agreement ratio), and p_e is the expected agreement when both annotators assign labels randomly. p_e is estimated using a per-annotator empirical prior over the class labels.

For each experiment and each task 25 pairwise comparisons were calculated (see Tables 1 and 2). The diagonal of the tables shows the self-comparison, which is by definition always equal to 1. Numbers in brackets indicate the number of images classified.

In what follows, the detailed procedures and results of the two classification experiments are outlined.

Experiment 1—Image Classification Results

As a first step, the images were distributed to annotators. Each person was asked to classify the images with the provided labels (set 1: fruit/non-fruit and set 2: formal/informal), where first the entire image set was classified using only label set 1, and in a second round the entire image set was classified again only using label set 2. For this experiment, no supplementary details, or definitions with regard to the labels were provided, relying solely on the annotators' own knowledge, intuition and interpretation.

The results from experiment 1 are presented in Table 1 below, showing the similarity scores (κ).

Table 1. Overview of similarity scores across the 5 annotators for experiment 1, applying label set 1 (upper panel) and label set 2 (lower panel).

Task_1	**User1**	**User2**	**User3**	**User4**	**User5**
User1	1.000 / (392)	0.928 / (392)	0.892 / (392)	0.907 / (392)	0.886 / (392)
User2	0.928 / (392)	1.000 / (392)	0.892 / (392)	0.938 / (392)	0.897 / (392)
User3	0.892 / (392)	0.892 / (392)	1.000 / (392)	0.923 / (392)	0.923 / (392)
User4	0.907 / (392)	0.938 / (392)	0.923 / (392)	1.000 / (392)	0.918 / (392)
User5	0.886 / (392)	0.897 / (392)	0.923 / (392)	0.918 / (392)	1.000 / (392)
Task_2	**User1**	**User2**	**User3**	**User4**	**User5**
User1	1.000 / (392)	0.330 / (392)	0.252 / (392)	0.316 / (392)	-0.091 / (392)
User2	0.330 / (392)	1.000 / (392)	0.210 / (392)	0.306 / (392)	0.153 / (392)
User3	0.252 / (392)	0.210 / (392)	1.000 / (392)	0.051 / (392)	-0.031 / (392)
User4	0.316 / (392)	0.306 / (392)	0.051 / (392)	1.000 / (392)	-0.028 / (392)
User5	-0.091 / (392)	0.153 / (392)	-0.031 / (392)	-0.028 / (392)	1.000 / (392)

Table 1 presents the pairwise comparisons of agreement scores across the five annotators applying the label sets for Task 1 (fruit/non-fruit) and for Task 2 (formal/informal). For Task 1, the agreement across the five annotators is relatively high with the score varying between 0.8 and 0.9. For

Task 2, a sharp drop in agreement scores compared to Task 1 is noted, with some scores falling even below zero (-0.2), with zero as an indication of chance agreement.

Experiment 2—Image Classification Results

In this experiment, the same setting as in the previous was given; however, at this time detailed definitions of the labels fruit/non-fruit and formal/informal were provided. This was done in order to determine whether the agreement among annotators would be any different than in the previous experiment. The definitions were derived from available monolingual English language dictionaries, e.g., Collins English Dictionary.

- Fruit: fruit or a fruit is something which grows on a tree or bush, and which contains seeds or a stone covered by a substance that you can eat. (e.g., strawberry, nut, tomato, peach, banana, green beans, melon, apple)
- Non-fruit: images that do not feature any type of fruit (for fruit definition see above)
- Formal: arranged in a very controlled way or according to certain rules; an official situation or context.
- Informal: a relaxed environment, an unofficial situation or context, disorderly arrangement

Results from experiment 2 are presented in the following Table, showing similarity scores across the five annotators.

Table 2. Overview of similarity scores across the 5 annotators for experiment 2 label set 1 (upper panel) and label set 2 (lower panel).

Task_1	**User1**	**User2**	**User3**	**User4**	**User5**
User1	1.000 / (392)	0.943 / (392)	0.913 / (392)	0.928 / (392)	0.913 / (392)
User2	0.943 / (392)	1.000 / (392)	0.886 / (392)	0.912 / (392)	0.866 / (392)
User3	0.913 / (392)	0.886 / (392)	1.000 / (392)	0.923 / (392)	0.928 / (392)
User4	0.928 / (392)	0.912 / (392)	0.923 / (392)	1.000 / (392)	0.913 / (392)
User5	0.913 / (392)	0.866 / (392)	0.928 / (392)	0.913 / (392)	1.000 / (392)
Task_2	**User1**	**User2**	**User3**	**User4**	**User5**
User1	1.000 / (392)	0.168 / (392)	0.216 / (392)	0.255 / (392)	0.167 / (392)
User2	0.168 / (392)	1.000 / (392)	0.188 / (392)	0.095 / (392)	0.419 / (392)
User3	0.216 / (392)	0.188 / (392)	1.000 / (392)	0.094 / (392)	0.358 / (392)
User4	0.255 / (392)	0.095 / (392)	0.094 / (392)	1.000 / (392)	0.089 / (392)
User5	0.167 / (392)	0.419 / (392)	0.358 / (392)	0.089 / (392)	1.000 / (392)

Table 2 presents the pairwise comparisons of agreement scores across the five annotators applying the label sets for Task 1 (fruit/non-fruit) and for Task 2 (formal/informal). Looking first at Task 1, the agreement across the five annotators is again relatively high, similar to those presented in Table 1, Task 1, with a score ranging between 0.8 and 0.9 as well. Looking next at Task 2, a considerable decrease in agreement scores compared to Task 1 can be noted, with scores ranging between 0.4 and ~0.09.

Discussion

For task 1 in both experiments, results showed that the average agreement was high, but increased slightly when definitions were provided in the second experiment (from 0.928 to 0.930). This is also a behaviour one would expect from non-human labelling systems (e.g. Neural Networks), given the clear correlation of the task and the graphical elements present in the figure.

For the second task, the average agreement was low in both experiments, and increased only slightly when definitions were provided (from 0.317 to 0.364). This was also expected, given the idiosyncrasies regarding classification of cultural aspects.

Additionally, the overall agreement among female and male classifiers was calculated. The overall agreement for the female classifiers, task 1 was 0.945 and for the male classifiers, task 1, was 0.934. For task 2, the agreement for the female classifiers was 0.318 and for the male classifiers was 0.242. Although there is no statistically significance with such a small sample, that may also indicate that gender related aspects can influence the levels of agreement in classification tasks.

Conclusions

In conclusion, our results from this experiment showed that classifying historic food images according to both physical and cultural aspects are fairly different tasks. While defined physical patterns are a domain in which the machines have acquired the state-of-the-art, cultural features pose a much more challenging task for both machines and humans, requiring at times different strategies to the commonly applied approaches. It is obvious that food interpretation is framed by an interdisciplinary science that includes primarily sociological, technological, economic, and cultural dimensions. And our findings support the proposition that food interpretation is time- and place-specific, and it is individual, not easily generalisable.

This paper aims to lay the grounds for further research in which it is intended to compare human and machine annotation performances. The analysis of inter-annotator-agreement showed so far that humans are able to capture subtle nuances and cultural features contained in images. In future experiments the aim is to compare human to machine annotations, as this can open ways to enhance image searches for digital cultural collections, a development that is to-date still in its infancy. A comprehensive discussion of the scientific work along with the final results of the study is available in Abgaz et al. (2021).

Funding

The ChIA project is funded by a go!digital Next Generation grant (GDNG 2018-051) of the Austrian Academy of Sciences.

Conflict of Interests Disclosure

The authors declared no conflict of interest.

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Climax: A historical script´s AI transformation for human behavioural estimation

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Abstract: This article presents an AI pilot project, derived from and applied to a Christian cultural heritage text, called Climax. This book is characterized by unique value, dimension and tone from a psychological point of view. Indeed, it can be used as an exceptional tool for diagnosis, treatment, and prediction of individual behaviours, from both a psychological and a theological point of view. Within this framework, the initial goal of the project presented herein, is to explore specific capabilities provided by machine learning, with field of interest that of Climax while focusing research on the area of supervised learning. In this way, a route is opened in behavioural research, and especially in the field of personality behaviour. According to the text under consideration, all human mental states result from a dipole of behaviour, which is summarized in: *passions vs virtues*; a negative value is given to the first category of behaviour (passions), while a positive value is given to the latter (virtues). The ascent of people to higher spiritual levels presupposes the cultivation of virtues and the healing of passions, while in turn these actions allow for a peaceful earthly life. Conversely, the descent of people to lower spiritual levels comes by the development of passions and the elimination of virtues, which leads to pathological states.

Keywords: *Artificial Intelligence—Historical Script—Human Behavioural Estimation*

CHNT Reference: Myridis, N. and Sarakatsianou, D. (2022). 'Climax: A historical script´s AI transformation for human behavioural estimation', in Börner, W., Rohland, H., Kral-Börner, C. and Karner, L. (eds.) *Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020.* Heidelberg: Propylaeum.
doi:10.11588/propylaeum.1045.c14478

Introduction

Today, applications of Artificial Intelligence (AI) are increasingly used in industry (Lee et al., 2018; Parunak, 1996), in companies (Machová and Vochozka, 2019; Sterne, 2017) and other areas e.g. in museums (Burgard et al., 1999; Villaespesa and Murphy, 2021), in medicine (Chiang and Dey, 2018; Hamet and Tremblay, 2017; Ramesh et al., 2004), in education (McArthur et al., 2005). It is well known that one tool of AI is machine learning (Bernard, 2021), that is the way through which a computer system (machine) can acquire intelligence. In other words, AI as science seeks to make machines acquire a basic human ability, the ability to understand and learn things, to become intelligent systems (Negnevitsky, 2005). This ability is achieved through three ways of learning: supervised learning, unsupervised learning, and reinforcement learning (Bernard, 2021). A basic goal of machine learning, then, is to create automated services for understanding a dataset, so that those services can be used to solve different problems that require intelligence. Some of these are problems: classification, prediction, association analysis, clustering, pattern recognition, planning, etc.

(Bernard, 2021). The first step required is learning, i.e. computer systems learn from data, specifically through their descriptive features. The next step is to enable systems to make decisions by observing situations –just like humans do– without being explicitly programmed to do so.

Taking into account all these possibilities of machine learning, an AI project is proposed here. More specifically, this is a cultural heritage project involving the elaboration of a Christian text, which at the same time, in addition to being a theological text, can also be described as a psychology textbook, or more precisely as a “manual” for diagnosing, treating and predicting individual behaviors. That is, the text is related to the field of personality psychology (Pervin, 2003), but also the field of 42ehaviour change (Bellg et al., 2004; Moncher and Prinz, 1991). Besides, their integration with the field of informatics gives new opportunities in 42ehaviour42l research, but also in the organization of knowledge about human 42ehaviour (Spruijt-Metz et al., 2015).

The text being studied is therefore called the “Climax”; it is a text that provides an empirical model for the development of the human personality, which is structured in steps of the scale, that those who follow them will pass from the lowest to the highest levels of the spiritual ascent of the soul. The model, therefore, is based on a theological point of view, in fact quite ascetic, which does not necessarily coincide in all its points with the secular conception. In other words, Climax proposes its value system, through which it looks to the prospect of the salvation of the soul. Salvation leads to an earthly bliss, earthly happiness, which every human being undoubtedly seeks in every age. In turn, this earthly bliss leads to future heavenly glory. But let us look in more detail at some useful facts about this Christian text.

Climax’s structure

There is a historical script in the Christian Literature, written in the first period of unified Christianity, which could be considered as the primary theological text, in value and uniqueness, after the Bible. The title of this script is ‘Climax’ (= the Ladder) and it was written by St. John of Sinai (or, Climacus). This text was written in the 6th century AD. in the Greek language of that period, following a long period (ca. 40 years) of St. John’s rigorous ascetic life on Mount Sinai. The script is an offspring of the empirical progress of St. John in spiritual perfection in Christ. It is undoubtedly an entity of world cultural heritage. The aforementioned book ‘Climax’ is thus important for the Christian Church that one Sunday each year has been dedicated to it, a dedication which is maintained until today, e.g. in the Orthodox Church. It should be noted that ‘First, the Ladder was written specifically for monks in a cenobium. And, second, the work is relevant to laypeople, too’ (Chryssavgis, 2004, p. 23).

The text is structured in 30 chapters – the 30 steps of the Ladder – which are the steps of man’s ascent to spiritual (in Christ) perfection; this perfection is achieved with the virtue of love (30th step). One of the proposed segmentations regarding the organisation of the text is given as (Climacus, 1982, pp. 11–12): (i) ‘The Break with the World’ (Step 1–3) (ii) ‘The Practice of the Virtues-Active Life’ (Step 4–26) (iii) ‘Union with God-Contemplative Life’ (Step 27–30). In addition to the previous general structure of the overall book, there is an internal structure per chapter that includes: introduction, definitions, presentation of the subject under examination, and conclusions (Chryssavgis, 2004). The virtues and passions of man coexist in the work; each person should follow virtues and should avoid passions. It is obvious throughout the text that two opposite poles are dominant, the virtues and the passions, which are the fundamental entities of human behaviour.

The text has its inherent and even unique logic, as well as a related exceptional intelligence. For example, the behavioural entities (passions/virtues) that are presented in the text of Climax are very well delimited, with specific properties, positions, and relationships (of hierarchy, inheritance, causality, etc.). The latter effortlessly provides the opportunity to move to the level of Artificial Intelligence (AI). Therefore, adapting the content of the text to an AI format is not just a challenge, it is a must. Furthermore, what is definitely the primary application of Climax in (real-time) applications draws from its unique advantage that is to provide interconnections among individual components of human personality, and therefore of behaviour, i.e. virtues and passions; moreover, to provide the logical path of their evolution, as well as of human behaviour. Therefore, a robust estimation of human behaviour results.

Method

It is obvious that machine learning provides a wide range of advanced capabilities. However, the article at hand focuses on supervised learning, which is one of the ways in which machines learn. In this case, computer systems accept input data (A) and their corresponding output data (B). The *A to B* type of learning, i.e., input to output mappings, is the most common method in machine learning. Paradigms of this type of learning are online advertising and machine translation. For instance, in the first paradigm, information about potential customers (e.g. age, place, interests, selection of previous advertisements) and advertisements (e.g. advertisement type, advertisement product) are the input and output data. Therefore, the data feeding of an AI system is a very crucial factor for its advanced function. In other words, the dataset is a critical factor in achieving machine learning, while moreover, the more data fed to it the better prediction is achieved.

Consequently, understanding data that will be used in machine learning is a critical task, while the abundance of data significantly affects the whole learning task too. In the next paragraphs the types of data which can be mined from the Climax's text is presented as well as their nature and their amount. In more detail:

(1) types of data

Climax's text describes different somatic and psychic conditions in which a person may find himself. These conditions reflect specific behaviors, which can be distinguished into two broader behavioral entities, passions and virtues. In the text, passion (πάθος/ páθos /) is considered to be a negative state (thought/ feeling/ desire or action), which is so strong that it wins over logic and determines the general patterns of man's behavior. A behavior, however, that goes away from the goal of (eternal) salvation of man. On the other hand, virtue (αρετή/ aretí is considered to be a positive state (thought/ feeling/ desire or action), which leads to the (eternal) salvation of man. Moreover, the snapshots of behavioral entities (e.g. mourning, untimely jesting, love, hate) -as already mentioned- have specific properties, positions, and relationships. Indeed, the following aspects can be found in the text:

(a) definition of snapshots. The following excerpt of the text is here as an example: "Mourning is the characteristic sorrow of a penitent soul who adds sorrow to sorrow" (Climacus, 1982, p. 43). This definition makes feasible the determination of fundamental characteristics connected to this specific behavior snapshot, i.e. its description.

(b) *positions of the snapshots*. It is observed for example, that each specific passion or virtue leads to (generates) other passions or virtues respectively. This creates a chain of passions or virtues, where each snapshot of behavior has a definite position. For instance, gluttony precedes lust in the chain of passions' occurrence.

(c) interconnections among snapshots. There are at least three fundamental interconnections among snapshots: *relationship of transition* (e.g. gluttony gives birth to lust, which in turn gives birth to untimely jesting), *relationship of opposition* (hate vs love) and *relationship of hierarchy* (there are eight fundamental passions that give birth to the rest passions). It should also be noted that, throughout the text, the sequential and dependent interrelationships of passions and virtues are apparent.

(2) data nature

Climax's text consists of unstructured data, although there is a logical structure in the way the data related to human behaviour are presented (e.g. path of evolution). However, the unstructured data are not systematically documented and accumulated into appropriately structured data structures.

(3) amount of data

The text is characterized by a very dense meaning; thus the information that refers to mental states is abundant. The latter can easily be understood, given that the overall content of the Climax book in English, i.e. 'The ladder of divine ascent' extends to 129 pages (Climacus, 1982). Indeed, as will be seen in the following application scenario (see Figure 3), 23 passions and 31 relationships have been identified on a single page. It can therefore be estimated how large will be the total amount of data regarding the whole text. The critical conclusion is therefore that the amount of data that can be extracted from the text is very large, and thus it is undoubtedly enough to train the computer system.

In addition, the snapshots of the couple of behavioral entities it is possible to be organized into three parts based on the three-part division of the soul –which appears already from antiquity in the teaching of Plato, known as *Plato's Tripartite Soul Theory* (Fancher, 1996)– since, according to Christian teaching, soul is the seat of personality (see for instance: homilies of elder Athanasios[1]). These three parts are intellect, reason, and spirit. The first part concerns speech and thought, the second refers to emotion and the third one concerns desires which are so strong and lead to action. Finally, the collection of data is implemented by manual labeling, which is a de facto and tried way to acquire a dataset in order to create a behaviour 'detector'. Thus, in as much as AI is able to analyze complex data, then, it can be used, in this project, to diagnose, treat and predict human behaviors, as will be briefly shown in the next section.

AI estimation of human behaviour via Climax

At a practical level, the algorithmisation of the production of behavioural knowledge presupposes the transcription, coding, and storage of the empirical data of Climax in computer systems. Thus an 'intelligent' tool can be created for understanding people's actions, which is able to "predict" and "explain" their behaviour. Two approaches seem possible: on the one hand, a knowledge base can be constructed, which will "estimate" behaviour based on what he knows, while on the other hand, a learning machine can be constructed which will "explain" behaviours based on the creation of new data structures, namely, new mental patterns.

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[1] http://www.saintnicodemos.com/articles/athanasios.php

In this context a class called ‘soul’ can be created, which contains the three fundamental powers/parts of the soul, according to Christian teaching (St. Gregory Palamas), namely, nous, logos. and pneuma (intellect, reason, and spirit). The subclasses (i.e. virtue and passion) inherit all the attributes from the parent class ‘soul’; however, the subclasses possess their own specific attributes. These attributes are their name, their product and their order (which is a number that indicates the number of products that a virtue or a passion produces) (see Fig 1.). An identification number is also defined for each path in the complexity diagram, which is characterised as ‘id-path’.

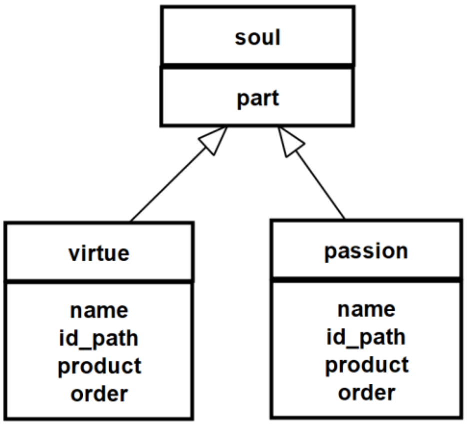

Fig. 1. Inheritance diagram of Climax © Authors

Moreover, there is additionally the possibility of knowledge representation in order to extract and display the relationships between virtues and passions; the latter representation leads to respective complexity diagrams (Myridis, 2020) as a skeleton/spine on which the whole work is built. The behavioural entities (virtues, passions) are the nodes of complexity diagrams, while the edges in these diagrams are the interconnections among the entities. Two typical examples of complexity diagrams in Climax are given below.

In Figure 2 a snapshot is schematically rendered regarding the relationship diagram of the passion of avarice. More precisely, this figure highlights a path of evolution of the avarice passion. It follows from this graph that the products of avarice are anger and effort while it is itself a product of the passion of unbelief.

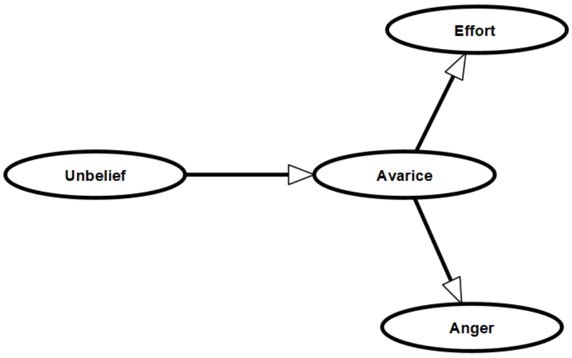

Fig. 2. A path of evolution (snapshot) of the passion of avarice © Authors

In Figure 3 another snapshot is depicted displaying the products of avarice which are: hatred, thefts, envy, separations, enmities, storms, remembrance of wrong, hard-heartedness, murders.

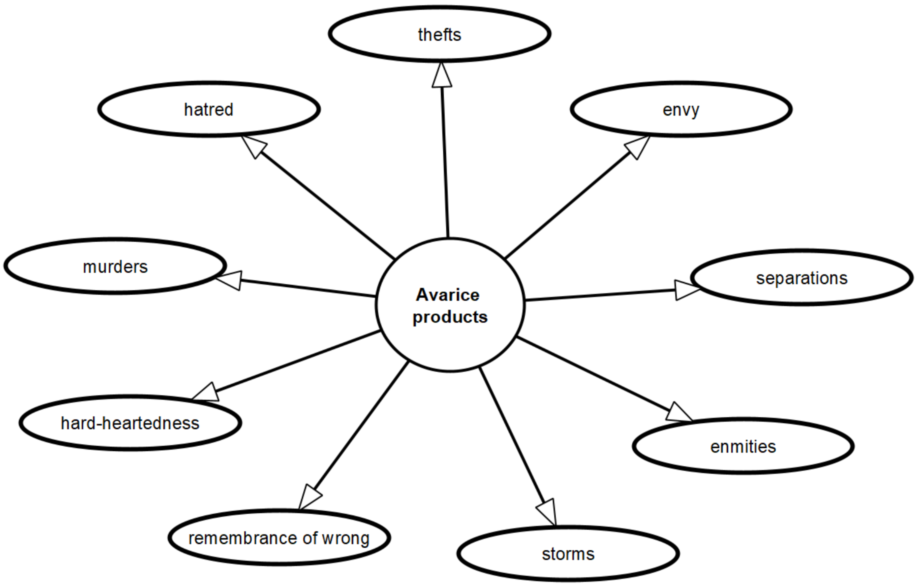

Fig. 3. The products of avarice © Authors

It is obvious therefore that a set of examples of behaviours can be extracted from the text, which ones are marked as positive or negative. These examples are then classified into categories which have specific characteristics. When structured data have been created, a prediction can be made: an unknown behavior can be classified into a specific category (output data), based on the description of all behaviors (input data), i.e. it can be decided whether it is a passion or a virtue.

It is also possible, for example, to identify the chain of relationships that intercorrelate passions. The text of Climax reveals that a behavior A generates another behavior B. Therefore, an AI system can be trained to decide which one is the input and which one is the output. A characteristic example of representation of negative behaviors (passions) sequences is shown in Figure 4. Some passions are fundamental (e.g. despondency, vainglory, and gluttony) and others are non-fundamental (e.g. conceit, dejection, despondency). It is also observed that some relationships among passions are stronger. This means that, e.g. hardheartedness frequently is born of insensitivity.

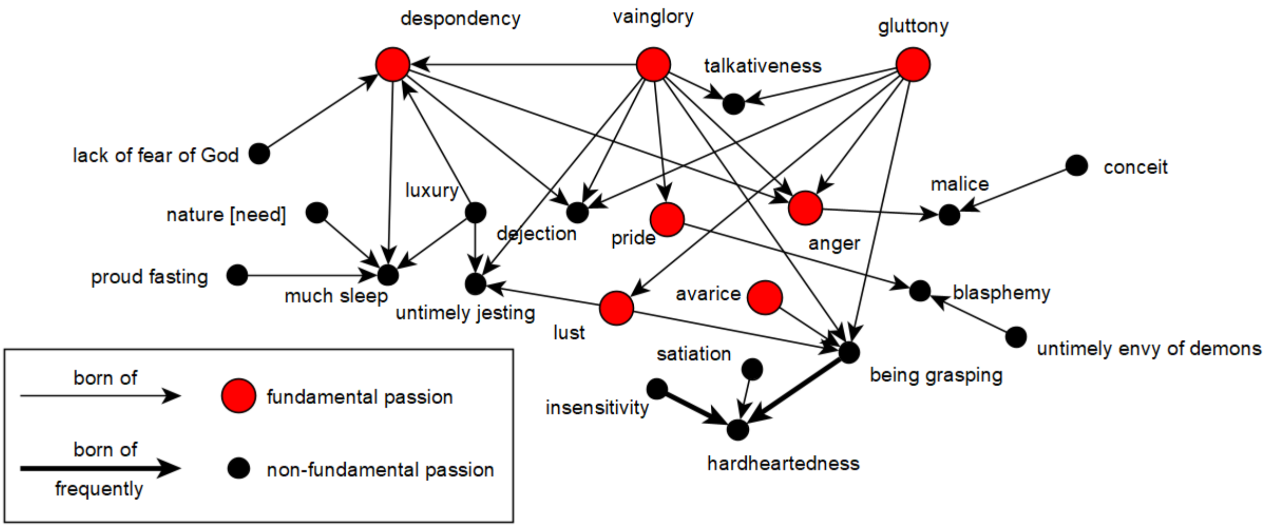

Fig. 4. Complexity diagram of passions © Authors

In this context, a group of people (e.g. psychologists, spiritual fathers) can study the behaviors of individuals and be able to discover the main cause of a passion. In fact, the cause sought obviously refers to another (radical) passion, which must be treated. Climax's text concludes that, in general, all passions can be healed directly by humiliation (!), a virtue which however is difficult to be realized. However, alternatively, there are also longer paths to eliminate passions via gradual progress in virtues.

Conclusion

The usefulness of AI in the case of Climax is manifold and extends to a variety of areas of interest, e.g. psychology. The overall text, with its structure and development, as well as with the analysis of the psychical untrodden of human personality, provides a profile of the human soul and an approach to human behaviour. It also opens new horizons of research and challenges, such as for instance is the research focusing on the degree of Climax's approach to the real status of human character and behaviour. Both the revelation of aspects of human personality by terms, means and applications of AI, as well as the estimation or interpretation of behaviours, are innovative achievements provided in our time by a historical text of centuries, i.e. that of Climax. Moreover, there is of course the alternative way of implementing this project by using neural networks or deep learning algorithms.

Finally, it should be states that the original text: (a) carries out an in-depth examination of behaviors; (b) demonstrates the unconscious interrelationships among behaviors, i.e. the interconnection of passions and/or virtues; (c) provides key answers to the challenges personality psychologists face; (d) grounds all the aforementioned onto salvage criteria, which not only concern a future (eternal) peace but also an earthly one.

Funding

The research was not funded.

Conflict of Interests Disclosure

Authors have no conflict of interest to declare.

Author Contributions

Conceptualization, Project Administration, Supervision, Validation, Writing – review & editing: Nikolaos Myridis

Data curation, Investigation, Visualization: Dimitra Sarakatsianou

Formal Analysis, Writing – original draft, Methodology: Nikolaos Myridis, Dimitra Sarakatsianou

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Session:
Machine Learning in Archaeometry

Johannes TINTNER | Bernhard SPANGL | Michael MELCHER

Call

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Michael MELCHER, University of Natural Resources and Life Sciences, Vienna, Austria

Keywords: *Tree-Based Methods—Neural Networks—Support Vector Machines—Self-Organizing Maps*

Machine learning algorithms faced a considerable breakthrough in very different fields of application, where huge amount of data are collected. They started to be developed in the 80s of the last century and can roughly be categorized as either supervised or unsupervised. Representative members of supervised learning are regularization methods for prediction and classification, additive and tree-based models, neural networks and support vector machines. Representative members of unsupervised learning are clustering algorithms, self-organizing maps, principal and independent component analysis and multidimensional scaling.

Modern analytics in archaeometry often produce such huge data sets. Therefore, it seems natural that a rising number of applications can be realized. A literature search on the platform “Scopus” found between 2010 and 2017 each year between one and five publications dealing with machine learning methods in an archaeological context. In 2018 the number increased to 12 and in 2019 to 19. We can assume this trend will proceed exponentially.

Especially spectroscopic methods like multi- or hyperspectral imaging demand advanced statistical methods. But also prediction models for the age of wood have been established with the help of machine learning methods. Classification tasks regarding pattern recognition of pottery, sex determination in human remains or the restoration of ancient texts are typical examples, where methods of machine learning can be applied. The session invites submissions dealing with the application of machine learning methods in archaeometric questions. Please indicate the specific methods applied and why these methods were chosen for the specific problem. Describe the methodological approach in a widely understandable way and discuss advantages and disadvantages in relation to the problem.

Effectiveness of DTM Derivatives for Object Detection Using Deep Learning

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Abstract: Deep learning models have achieved significant performances in identification and localization of objects in image data. Researchers in the remote sensing community have adopted such methods for object recognition in remote sensing data, especially raster products of Airborne Laser Scanning (ALS) data such as Digital Terrain Models (DTM). Small patches of larger DTMs, where pixels represent elevations, are cropped to train deep learning models. However, due to the variation in elevation values for the same object in two different regions, deep learning models either fail to converge or take a long time to train. To alleviate the problem, a local preprocessing step such as normalization to a fixed range or local patch standardization is necessary. Another solution is to first calculate other raster products where the pixel values are calculated based on the surrounding pixels within a certain range. Examples of such rasters are Simple Local Relief Models (SLRM), Local Dominance (LD), Sky View Factor (SVF), and Openness (positive and negative). In this research, the effect of using the aforementioned DTM derivatives are studied for detection of historical mining structures in the Harz Region in Lower Saxony. The well-known Mask R-CNN model is trained to produce bounding boxes, labels, and segmentation maps for each object in a given input raster.

Keywords: *Archaeology—Digital Terrain Models—Deep Learning—Object Detection—Lidar*

CHNT Reference: Kazimi, B., Malek, K., Thiemann, F., and Sester, M. (2022). ‘Effectiveness of DTM Derivatives for Object Detection Using Deep Learning’, in Börner, W., Rohland, H., Kral-Börner, C. and Karner, L. (eds.) *Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020.* Heidelberg: Propylaeum.
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Introduction

Deep neural networks achieve tremendous results in object detection. They work well with color images, but researchers have shown that elevation data obtained from airborne laser scanning can also be used by deep neural networks for detection of objects and relevant structures. One of the main products of airborne laser scanning data is Digital Terrain Model (DTM), which represents the ground surface as a rectangular grid where each pixel is assigned an elevation value. The elevation values are exploited to extract useful properties to infer the types, and shapes of different objects and structures in the terrain. Deep learning has been used to detect structures related to historical mining, and archaeology, among others (Kazimi, Thiemann, and Sester, 2019a, 2019b; Kazimi et al., 2018; Politz, Kazimi, and Sester, 2018). The pixel values in natural images range from 0 to 255, and for the deep learning models to converge, it is important to scale the images to have a smaller range, usually $[0,1]$ or $[-1,1]$. Scaling a large DTM globally in one of these ranges cause the values to have very small variations relative to their neighbouring pixels and thus, it makes it hard for the model to learn. A common method is to divide the DTM into smaller grids and scale the values locally (Kazimi, Thiemann, and Sester, 2019b). Other researchers used a derivative of the DTM called Simple Local Relief Model (SLRM) to train deep learning algorithms for detection of archaeological objects (Trier, Cowley, and Waldeland, 2019; Verschoof-van and Lambers, 2019). SLRM normalization removes the effect of absolute height differences and helps the model learn better. Other derivatives of DTM include Local Dominance (LD), Sky View Factor (SVF), and Openness (positive and negative), among others, each of which help visualize objects and structures in the terrain in a different manner (Kokalj and Hesse, 2017). The goal of this research is to find out which of these DTM derivatives help in automating detection of objects and structures. This article is organized to include related work in deep learning and its applications in archaeology, contributions of this research as a case study, evaluation of results and finally a summary and outlook for future research directions.

Related Work

Deep learning methods have reached a considerable level of maturity on natural language processing and computer vision tasks for natural images. Recent indicators of this progress in natural language processing are Transformers (Vaswani et al., 2017) and other Transfer-based models, e.g. BERT (Devlin et al., 2019) and GPT-3 (Brown et al., 2020). Their counterparts in computer vision tasks are Image-GPT (Chen et al., 2020), HRNet (Sun et al., 2019; Wang et al., 2019), and EfficientNet (Tan and Le, 2019), among others. Inspired by this progress, researchers in other domains continuously find methods to incorporate deep learning techniques in their own research and projects. Archaeology is also among research fields that could make use of the progress in deep learning techniques. Verschoof-van and Lambers (2019) use deep learning to automatically detect archaeological objects in LiDAR data. The authors train the Faster R-CNN model (Ren et al., 2015) on a dataset of archaeological objects such as barrows, celtic fields, and charcoal kilns in the Netherlands. Trier, Cowley, and Waldeland (2019) use deep residual networks (ResNet) by He et al., (2016) to classify archaeological objects such as roundhouse, shieling hut, and small cairns in LiDAR data from Arran, Scotland. Other example applications of deep learning in archaeological research include the works of Bundzel et al. (2020), Gallwey et al. (2019) and Maxwell et al. (2020a; 2020b), among others.

Case Study

This research explores the use of object detection methods in archaeology using DTMs. Generally, deep learning models could be fed directly with DTM patches and be trained for automated detection of objects and structures of interest. DTMs contain elevation values for points on the terrain and do not have a fixed range of values, rendering them hard to perceive with the naked eye. For analysis and visualization, researchers use DTMs to generate relief rasters such as hillshade, SLRM, SVF, LD, Openness, slope and aspect, among others. The main concept behind this study is to see the impact of such relief rasters on detection of archaeological objects with deep learning. It is hoped that such rasters help deep learning models make better predictions, similar to how they help with visualization and analysis.

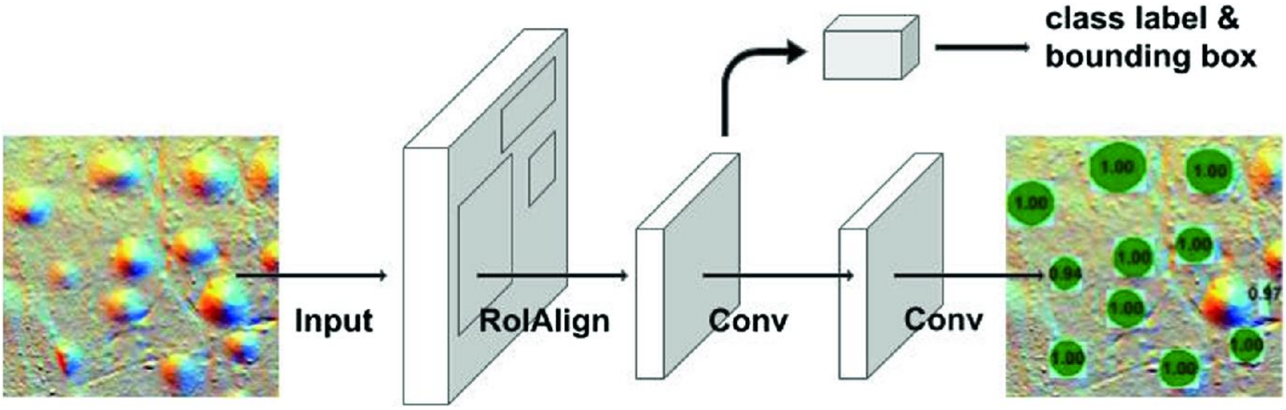

Fig. 1. Mask R-CNN architecture (© Kazimi et al., 2019a)

The well-known deep learning model called Mask R-CNN by He et al. (2017) is trained to detect terrain structures related to historical mining in the Harz Region in Lower Saxony. Mask R-CNN is designed to take input images and predict bounding box locations, segmentation masks and class labels for every object contained in the input. The architecture is illustrated in Figure 1.

The dataset is created from DTM data acquired from Lower Saxony, Germany and annotations for four structures including bomb craters, charcoal kilns, barrows and mining sinkholes. The DTM has a resolution of half a meter per pixel. Using the Relief Visualization Toolbox (RVT) (Kokalj and Somrak, 2019), relief rasters such as SLRM, SVF, LD, and Openness (positive and negative) are calculated from the DTM. Training examples of 128 × 128 pixels are cropped from the DTM and also the corresponding relief rasters from regions that contain an instance of the aforementioned four classes. The dataset is divided into training, validation and testing sets with splits of 80, 10 and 10 percent. Statistics for the annotated examples are shown in Table 1.

Table 1. Data statistics. Four categories, examples of which are split to 80, 10 and 10 percent for training, validation and testing, respectively.

Categories	**Training (80 %)**	**Validation (10 %)**	**Test (10 %)**	**Total (100 %)**
Bomb craters	909	113	113	1135
Charcoal kilns	836	104	104	1044
Barrows	1058	132	132	1322
Mining holes	2132	267	267	2666

The model is trained using the original DTM, as well as the aforementioned relief rasters separately. For each raster type, the model is trained for 100 epochs with a batch size of 4 and the Stochastic Gradient Descent (SGD) optimization algorithm (Bottou, 2012). Random rotations and flipping are used as data augmentation techniques to avoid overfitting. Evaluations are performed using the Mean Average Precision (mAP) at an Intersection over Union (IoU) threshold of 50 % (Everingham et al., 2010). The experiments are conducted using Python programming language, and Keras deep learning library (Chollet, 2015). Results of the experiments are shown in the next section.

Results

In this section, quantitative evaluation results are reported using the mAP value obtained on the test data by each model trained on the DTM and the DTM derivatives or relief rasters. Additionally, examples of predictions by each model are illustrated for qualitative analysis. Table 2 shows best mAP for each input type on the test data using best learned parameters for training and validation data during training.

Table 2. Evaluation Results: Models trained on the DTM and its derivatives have been evaluated on the test set using the best parameters obtained during training based on training and validation data. Values show mAP at IoU threshold of 50% where ***bold*** *indicates best.*

	LD	**SLRM**	**DTM**	**SVF**	**Openness (+)**	**Openness (-)**
Training weights	61.7	**62.8**	59.6	54.1	50.8	50.7
Validation weights	**58.8**	56.0	54.5	45.0	40.2	42.8

As observed in Table 2, SLRM and LD helps achieve higher mAP scores while SVF and Openness (both positive and negative) scores are lower than that of original DTM. Figure 2 shows examples of DTM for each category and the corresponding results and visualizations for each derivative examined in this research. The mAP scores are reflected in the illustrated examples. Even though the true positive rate for all the data types are similar, there are fewer false positives in the case of SLRM and LD than the others.

Summary

In summary, this research is conducted to see the impact of relief rasters created from DTMs on detection of archaeological objects. The main idea is that if relief rasters help humans in visualization and analysis of objects and structures, they should also help deep learning models perform better. Moreover, the study specially helps find the types of relief rasters more suitable for detecting structures such as bomb craters, charcoal kilns, barrows and mining sinkholes. The mAP scores shown in Table 2 and the illustrations in Figure 1 indicate that LD and SLRM are better derivatives, among those studied in this research. It is also concluded that relief rasters lead to better detection results compared to the original DTM. Further experiments are required to study the effect of different DTM derivatives for detection of other object categories and those in different regions, different data sources, and data resolutions.

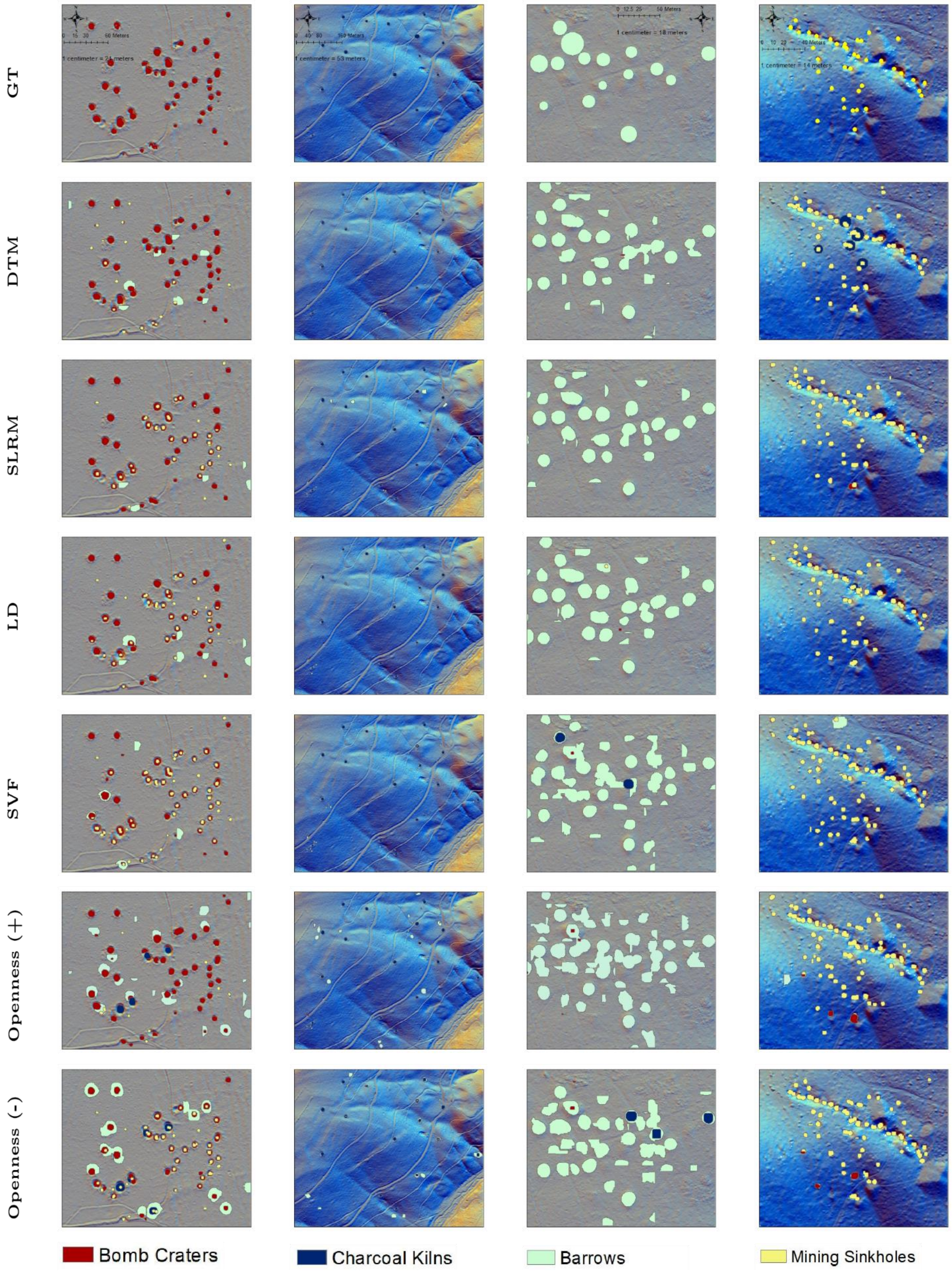

Fig 2. Detection results on four test regions containing the relevant structures. Each column illustrates the hill-shade relief of the region with ground truth (GT) labels and detection results by models trained on the DTM and its derivatives.

Funding

This research project is funded by the Ministry of Science in Lower Saxony.

Conflict of Interests Disclosure

All authors declare that they have no conflicts of interest.

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Session:
AI, ML and DL in satellite, aerial and ground based remote sensing

Apostolos SARRIS | Melda KÜÇÜKDEMİRCİ | Tuna KALAYCI

Call

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Keywords: *Articificial Intelligence—Machine Learning—Remote Sensing—Satellite—Geophysics—Aerial*

The recent years are experiencing an increasing number of Artificial Intelligence/Deep Learning/Machine Learning (AI/DL/ML) applications in various domains of Digital Humanities. Still, we are in the infant stage of their application and there are a number of limitations faced mainly due to the lack of a large volume of data that are required for their successful implementation.

Thanks to the development of UAVs, Lidar, Hyper-spectral and multispectral satellite imaging, multi-sensor and motorized equipment for geophysical surveys, a large quantity of data that cover extensive areas of the landscapes with high resolution is created, which can only be analysed efficiently by automated approaches leading towards a fast and accurate interpretation. This session is looking to build on the experience obtained from the application of various algorithms of AI/DL/ML on remote sensing data, spanning from satellite, aerial, ground based/geophysical and underwater surveys. We want to provide an exchange platform of the experiences acquired in image pre-processing, pixel-based classification, feature recognition, segmentation, and feature extraction and scene understanding in relation to the AI/DL/ML-based algorithms: comparison of networks, pre-trained models, hyper-parameter choices, APIs and in addition to these, discussion on obstacles, limitations, challenges, key bottlenecks and potential future direction of these new methodologies.

Testing the transferability of CarcassonNet

A case study to detect hollow roads in Germany and Slovenia

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Juergen LANDAUER, Landauer Research, Germany

Abstract: While (post)medieval hollow roads (sunken cart tracks) are hard to discern in the present-day landscape, they appear as distinct lines in LiDAR data. This offers opportunities to use automated detection methods to map these archaeological objects. However, the usability of such methods when used on an area unrelated to the area in which the method was developed, i.e., the transferability or generalization capability, remains an unanswered question. Therefore, in this paper, the transferability of CarcassonNet, a workflow combining a Deep Learning Convolutional Neural Network and image processing algorithms to map hollow roads in LiDAR data, is tested. CarcassonNet is trained on LiDAR data from the Veluwe region in the central part of the Netherlands. Subsequently, the workflow is tested on LiDAR data deriving from the Schurwald region in southern Germany and the Upper Carniola and Nova Gorica regions in northern and southwestern Slovenia respectively. These areas have different terrain and land-use compared to the Veluwe while the properties of the LiDAR data also differ. The results show that CarcassonNet is able to detect hollow roads as long as threshold moving is applied and the confidence threshold is re-determined. Differences in terrain and land-use seem to be of minor influence on the performance of CarcassonNet. However, it is apparent that differences in the quality of the LiDAR data, most probably the difference in average ground point density, do influence performance.

Keywords: *LiDAR—CNN—Hollow roads—Machine Learning—Transferability*

CHNT Reference: Verschoof van der Varart, W. and Landauer, J. (2022). ‘Testing the transferability of CarcassonNet. A case study to detect hollow roads in Germany and Slovenia’, in Börner, W., Rohland, H., Kral-Börner, C. and Karner, L. (eds.) *Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020*. Heidelberg: Propylaeum. doi:10.11588/propylaeum.1045.c14482

Introduction

Medieval hollow roads are linear, sunken trails caused by continuous passage of carts and other traffic through the landscape (Kirchner et al., 2020). These tracks are hard to discern in the present-day terrain but appear as distinct longitudinal objects in airborne Light Detection and Ranging (LiDAR) data (Kokalj and Hesse, 2017; Figure 1). This marked appearance offers opportunities to use Deep Learning methods to systematically map these hollow roads and reconstruct the historical route network.

The results of such endeavours can supplement and expand the knowledge gained from historical written sources and cartographic data (Kirchner et al., 2020). In archaeology, Deep Learning has successfully been implemented to detect discrete objects, such as barrows (Verschoof-van der Vaart et al., 2020), but has been scarcely used for more complex, large-scale patterns, such as roads (Traviglia and Torsello, 2017; Davis, 2021).

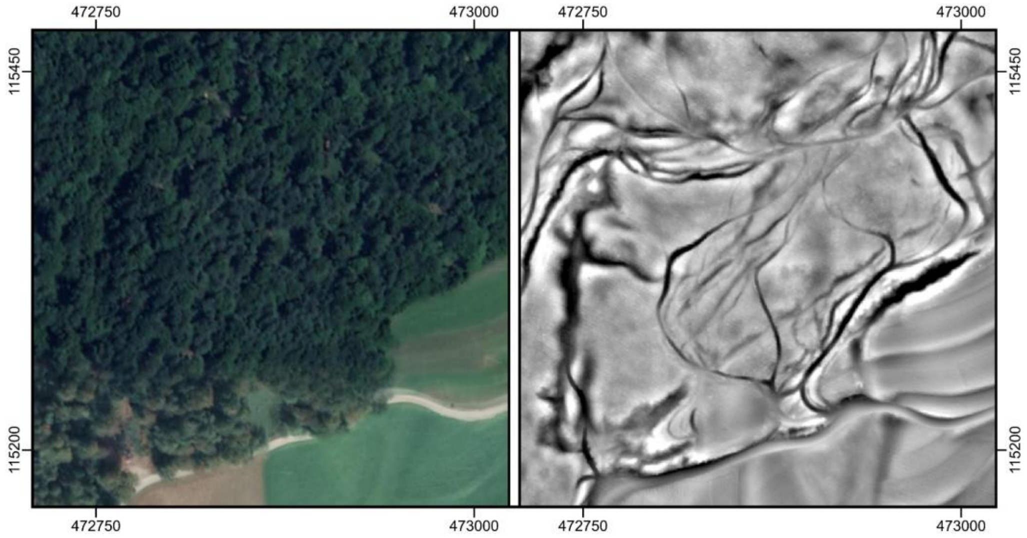

Fig. 1. An example of hollow roads on a recent aerial photograph (left) and on LiDAR data (right), visualized with SLRM (Hesse, 2010), from the Upper Carniola region, Slovenia (Coordinates in MGI 1901/Slovene National Grid, EPSG: 3912; © Authors).

This is in part because modern road detection methods (Abdollahi et al., 2020) do not translate well to the problem of hollow roads—typically several linear tracks with slightly different orientation and multiple overlaps—that lack the uniformity in shape and appearance of modern roads. Furthermore, hollow roads are often only partially preserved and regularly are dissected by modern landscape objects (Verschoof-van der Vaart and Landauer, 2021).

Therefore, to map hollow roads in LiDAR data, a workflow that combines Deep Learning and image processing algorithms has been developed (Verschoof-van der Vaart and Landauer, 2021). This workflow, named CarcassonNet, has successfully been trained and evaluated on the *Veluwe* area in the central part of the Netherlands. However, the transferability of CarcassonNet (or automated detection methods in general), i.e., the usability of the method on an unrelated area with either different topography, land-use and/or LiDAR data of different properties, remains an unanswered question in this research field (Kermit, Reksten and Trier, 2018; Cowley et al., 2020). As can be imagined, these factors can vary considerably on a regional or national or even international level, and a method that is unable to adjust to such different situations has little practical value for wide application. Therefore, studies in different environments are important to investigate the true potential of automated approaches in archaeological practice. In this paper, the transferability of CarcassonNet is investigated, i.e., whether our method, trained on Dutch LiDAR data, is able to detect hollow roads in LiDAR data from Germany and Slovenia.[1]

Research areas

CarcassonNet has been trained on LiDAR data from the western part of the province of Gelderland in the Netherlands, known locally as the *Veluwe* (see Table 1). This region consists of several north-south orientated ice-pushed ridges separated by relatively flat valleys. The area used (circa 97 km^2) is predominantly covered with heath and to a lesser extent with forest, and is interspersed with agricultural fields and areas of habitation (for a detailed overview of the Veluwe, see Lambers,

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[1] We are grateful to R. Hesse (Landesamt für Denkmalpflege Baden-Württemberg) and Ž. Kokalj (Research Centre of the Slovenian Academy of Sciences and Arts) for providing LiDAR data to test CarcassonNet.

Verschoof-van der Vaart and Bourgeois, 2019). The model has been tested on LiDAR data from the *Schurwald* region (Germany) and the *Upper Carniola* and *Nova Gorica* regions (Slovenia; see Table 1). The Schurwald is a wooded mountain range in the federal state of Baden-Württemberg in southern Germany. The area used (25 km^2) is covered with forest, crossed by numerous eroded stream valleys, and has various areas that have been cleared for agriculture and occupation (Hesse, 2013). The Upper Carniola region is a rugged area in the foothills of the Kamnik–Savinja Alps in northern Slovenia. The area used (circa 1.2 km^2) is predominantly covered with forest, villages, and some agricultural fields (Kokalj and Hesse, 2017). The Nova Gorica region lies on the border of the Karst Plateau in southwestern Slovenia. High lying plateaus with steep declines and many heavily eroded stream valleys characterize this landscape. The area used (circa 1.3 km^2) is covered with forest. In part of the area military trenches, comparable in morphology to hollow roads, are present (Kokalj and Hesse, 2017). All hollow roads in the Schurwald, Upper Carniola, and Nova Gorica area have been manually annotated by the authors, who both have ample experience in analysing LiDAR data.

The LiDAR data from the Veluwe, used for the training of CarcassonNet, has a raster resolution of 0.5 m and an average ground point density of 6–10 points per square meter. The resolution of the test data differs between 0.5 m (Upper Carniola) and 1.0 m (Schurwald and Nova Gorica). The average ground point density of the Slovenian data varies between 3 and 10 points per square meter, while the data from the Schurwald has a lower point density between 1 and 4 points per square meter (Table 1).

Table 1. The LiDAR datasets used in this research to train and test CarcassonNet.

Dataset	Area (sq. km)	Resolution	Average Point-density (pt. per sq. m)	Mean elevation	Min–Max elevation	General terrain	Main land-use
Veluwe (NL)	97.25	0.5	6–10	42	10–104	Ridges/valleys	Heath
Schurwald (DE)	25	1.0	1–4	172	13–254	Mountains	Forest
Upper Carniola (SI)	1.18	0.5	3–10	393	342–487	Hills	Forest
Nova Gorica (SI)	1.32	1.0	3–10	115	67–190	Karst	Forest

Methodology

The CarcassonNet workflow (Fig. 2) consists of three steps: preprocessing, classification, and post-processing (for an extensive overview of the methodology of CarcassonNet see (Verschoof-van der Vaart and Landauer, 2021). An important innovation in the CarcassonNet workflow is that multiple sections per single hollow road, as opposed to the entire road, are used as input images (comparable to the approach taken for Celtic fields in Verschoof-van der Vaart et al., 2020). This makes it much more cost-effective to create a sufficient training dataset.

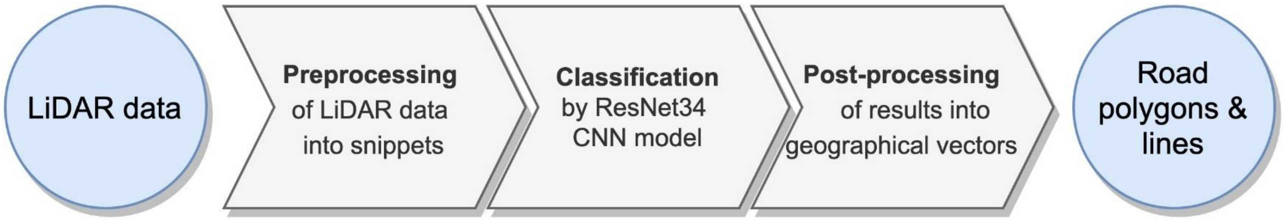

Fig. 2. Simplified representation of the CarcassonNet workflow; after Verschoof-van der Vaart and Landauer, 2021.

To create a training dataset, the first author manually annotated the LiDAR data from the Veluwe (97.25 km^2) in order to create a reference standard. Subsequently, in the preprocessing step the same LiDAR data was split into snippets of 64 by 64 pixels. For every snippet the percentage of overlap with the roads polygons in the reference standard was computed. Snippets with an overlap of 95% or more with the mapped hollow roads were put in a 'hollow road' class and only those with an overlap of 5% or less into the 'empty' class to create a binary dataset. Additional measures to balance the dataset resulted in training dataset of circa 32,000 snippets, with circa 16,000 snippets in both classes.

The second step of CarcassonNet consists of a Resnet-34 Convolutional Neural Network (He et al., 2016). A CNN is a hierarchically structured (image) feature extractor and classifier algorithm, loosely inspired by the animal visual cortex (Guo et al., 2016). These algorithms learn to generalize from given examples, i.e., a large set of labelled images, rather than relying on a human operator to set parameters or formulate rules. Furthermore, CNNs can be pre-trained on a large, generic dataset (for instance images of cats and dogs) and subsequently transfer-learned on a small, specific dataset (such as our dataset). In this research the CNN was only used for binary classification, a relatively simple task, which produces better detection results at a lower cost and effort (Guo et al., 2016), as opposed to a more complicated task such as segmentation. The ResNet-34 CNN was pre-trained on the ImageNet dataset (Russakovsky et al., 2015) and subsequently transfer-learned for twelve epochs on the LiDAR data from the Veluwe, following the "progressive resizing" training scheme recommended by the research institute *Fast.ai*. After training the CNN was tested on the data from Germany and Slovenia. To make the output of the CNN directly usable in a GIS environment, the detections are turned into geospatial vectors (polygons and lines; see Figure 3) by combining geospatial processing tools in *QGIS 3.4* and the image processing approach taken by Van Etten (2019).

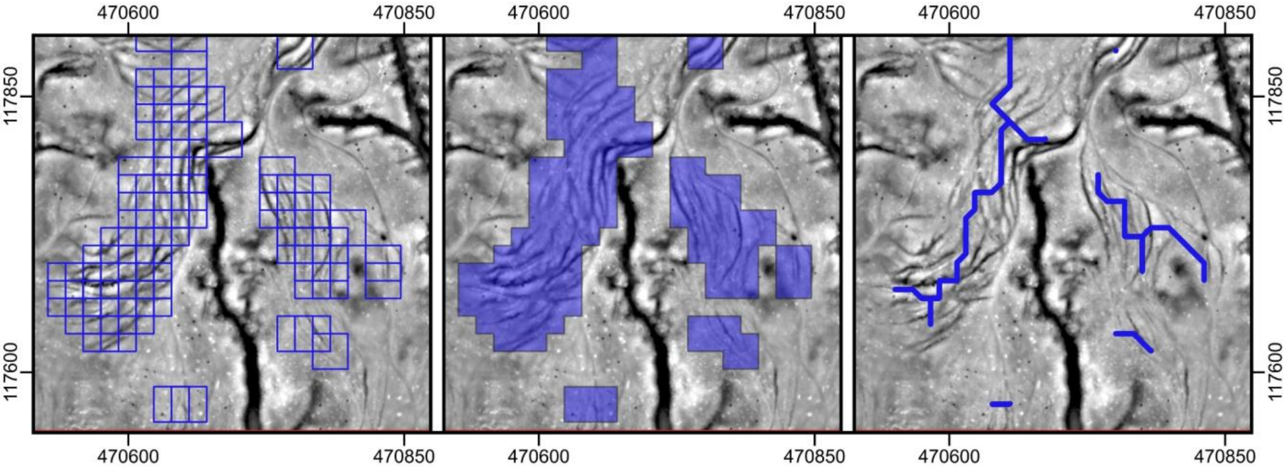

Fig. 3. Excerpts of LiDAR data, visualized with SLRM (Hesse, 2010), from the Upper Carniola region (Slovenia), showing: the results of the classification (left); the derived polygons indicating the location of the hollow roads (centre); and the derived lines depicting the route network (right; coordinates in MGI 1901/Slovene National Grid, EPSG: 3912; © Authors).

Results

To evaluate CarcassonNet, the area (in m^2) of true positives (TP), false positives (FP), true negatives (TN), and false negatives (FN) were determined following the approach taken in Verschoof-van der Vaart et al., 2020. Subsequently, Matthews Correlation Coefficient (MCC; Eq. 1) was calculated.

This metric is a reliable measure of the correlation between the observed and predicted binary classification, even if the classes are very imbalanced (Luque et al., 2019). Therefore, MCC is a better indicator of the quality of CarcassonNet, compared to other metrics such as F1-score or accuracy (Chicco and Jurman, 2020). MCC is bound between -1 and 1, where higher values indicate a better performance. The default confidence threshold for classification is typically set to 0.5. However, by changing the threshold (called threshold moving) and recalculating the performance metric, an optimal trade-off can be found, resulting in the highest MCC (Zou et al., 2016). During this research the optimal confidence threshold was empirically calculated (see Table 2). Finally, for comparison of the performance between the different datasets and other methods, the well-known metrics Precision (Eq. 2) and Recall (Eq. 3) were calculated as well (but see Luque et al., 2019). Precision measures how many of the selected items are relevant. Recall gives a measure of how many relevant objects are selected. The results of the experiments are shown in Table 2 and Figure 4. CarcassonNet has moderate to high performance on the Upper Carniola and Nova Gorica datasets, reaching a MCC of 0.37 (confidence threshold of 0.1) and 0.38 (confidence threshold of 0.8) respectively. However, the performance on the Schurwald dataset is lower, reaching a MCC of 0.25 with a confidence threshold of 0.75.

Equation 1:

$$MCC = \frac{(TP \times TN) - (FP \times FN)}{\sqrt{(TP + FP) \times (TP + FN) \times (TN + FP) \times (TN + FN)}}$$

Equation 2:

$$Precision = \frac{TP}{(TP + FP)}$$

Equation 3:

$$Recall = \frac{TP}{(TP + FN)}$$

Table 2. Results of the experiments on the different datasets.

Testset	Confidence	TP	FP	TN	FN	Recall	Precision	MCC
Veluwe (NL)[2]	0.8	4,967,470	7,243,900	88,839,400	2,664,868	0.65	0.41	0.47
Schurwald (DE)	0.75	320,430	243,300	22,486,100	1,950,250	0.14	0.57	0.25
Upper Carniola (SI)	0.8	79,500	40,823	732,832	146,928	0.35	0.66	0.38
Nova Gorica (SI)	0.1	88,280	81,928	884,790	120,283	0.42	0.51	0.37

Discussion

The results of the generalization experiments (Table 2) show that CarcassonNet, when trained on LiDAR data from the Netherlands, is able to detect hollow roads in other areas with different terrain, land-use, and on LiDAR data with different properties. However, the performance of the model decreases by 9–10 points on both Slovenian datasets, while the performance on the Schurwald dataset is 22 points lower. An important note to make is that the areas from Slovenia used for testing (2.5 km² in total) are considerably smaller than the Schurwald area (25 km²). This size difference might have

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[2] For comparison,the results of testing on the Veluwe dataset are reproduced from Verschoof-van der Vaart and Landauer (2021).

been of influence on the results, as the performance of a detection method can vary significantly between test datasets that have a different density of archaeological objects or in which the state of preservation of these objects varies (see Verschoof-van der Vaart et al., 2020).

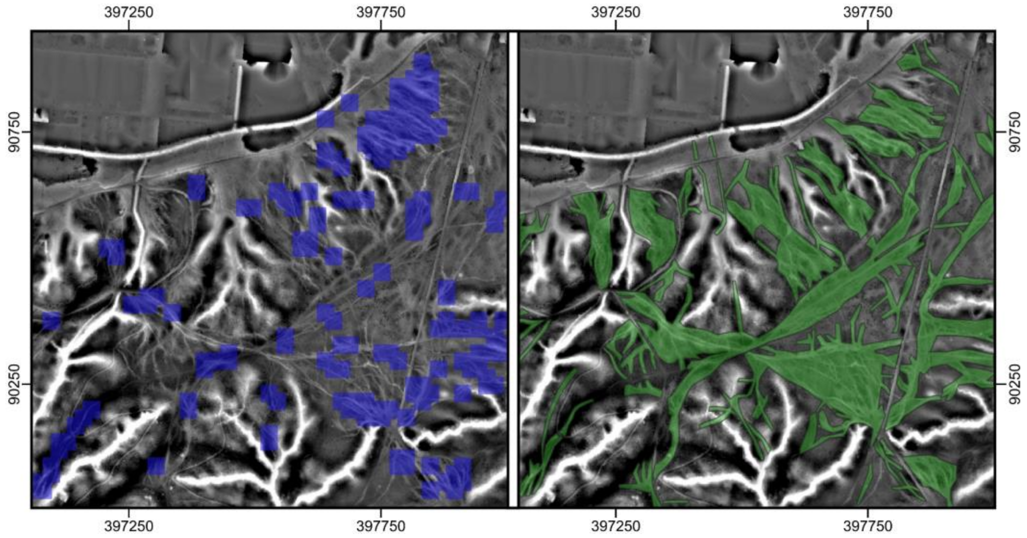

Fig. 4. Excerpts of LiDAR data, visualized with SLRM (Hesse, 2010), from the Nova Gorica region (Slovenia), showing: the results of the classification (left) and the manually annotated roads (right); coordinates in MGI 1901/Slovene National Grid, EPSG: 3912; © Authors).

The influence of the different terrain and land-use seems to have been minor, as no increase in FP is observed—the Precision is comparable for the German and Slovenian datasets and even better than on the Veluwe dataset. Therefore, a different cause needs to be sought for the lower performance, especially on the Schurwald data. Table 2 shows that the Recall on the Slovenian and in particular the Schurwald datasets is much lower, indicating that the recognition of hollow roads is the main detrimental factor. It was expected that this was caused by the difference in raster resolution between the datasets, which varies with a factor of two (0.5 versus 1.0 m). However, the comparable performance on the Nova Gorica (1.0 m resolution) and Upper Carniola (0.5 m resolution) datasets seems to indicate that this is also not of (major) influence. However, a comparison between the appearance of hollow roads in the different datasets shows that these occur much less pronounced in the Schurwald dataset (Fig. 5), which is probably related to the difference in average ground point density. The influence of ground point density on the ability of automated methods and humans to detect archaeological objects in LiDAR data has also been observed in other research, both for automated detection methods (Trier and Pilø, 2012; Dolejš et al., 2020) as well as for humans (Risbøl et al., 2013). Therefore, differences in LiDAR parameters, especially the ground point density, are probably detrimental on the performance of CarcassonNet.

Conclusion

This research shows that CarcassonNet, when trained on LiDAR data from the Netherlands, is able to generalize and detect hollow roads in data from Germany and Slovenia even though the areas have different terrain, land-use, and the LiDAR data has different properties. However, the performance of the model does decrease, in the case of the Schurwald area to the point that it is questionable if the method would be usable. Probably the difference in the average ground point density of the LiDAR datasets is the main negative influence on the performance. Therefore, further research will focus on improving CarcassonNet, to better cope with hollow roads in LiDAR data with different properties. For instance, by combining LiDAR datasets with varying properties and/or from different areas. Also the potential of Generative Adversarial Networks to increase the image resolution, and therefore increase the visibility of hollow roads in the LiDAR data will be explored (Ledig et al., 2017).

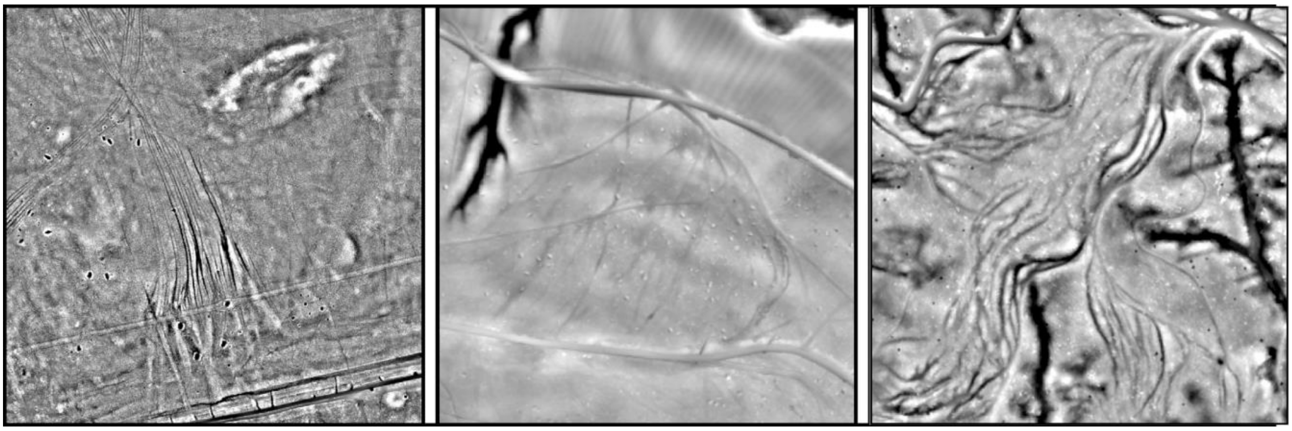

Fig. 5. Excerpt of LiDAR data, visualized with SLRM (Hesse, 2010), showing the difference in appearance of hollow roads in the different areas, from left to right: Veluwe, Schurwald, Upper Carniola (scale 1:5000; © Authors).

Funding

This research was in part supported by the Data Science Research Programme (Leiden University).

Conflict of Interests Disclosure

The authors have no competing interests to declare.

Author Contributions

Conceptualization, Data curation, Formal Analysis. Investigation, Methodology, Project Administration, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing: WV & JL
Visualization, Funding acquisition, Project Administration: WV
Software: JL

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Mag-Net

Improving magnetometer interpretation workflows with semantic segmentation

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Abstract: This paper presents a novel application of convolutional neural networks to the detection of archaeological ring ditches in gradiometer data in the UK. The Unet and ResUnet models applied in this study achieved an overall accuracy of 0.7 mIoU on a test dataset with minimal cost spent in pre-processing the data, demonstrating that machine learning on gradiometer data is commercially viable and can pave the way for a reduction in costs and time spent manually digitising features.

Keywords: *Machine Learning—Semantic Segmentation—Automatic Interpretation—Magnetoetry—Commercial Geophysics*

CHNT Reference: Wolf, J., Pope-Carter, F., and Johnson, P. S. (2022). 'Mag-Net. Improving magnetometer interpretation workflows with semantic segmentation', in Börner, W., Rohland, H., Kral-Börner, C. and Karner, L. (eds.) *Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020*. Heidelberg: Propylaeum.
doi:10.11588/propylaeum.1045.c14483

Introduction

Practitioners of commercial geophysics in Britain have met increasing demands for large-scale surveys with the development of multi-sensor, cart-based, motorised, and modular survey systems to improve efficiency and speed of data-collection. By rising to these physical challenges, however, the concomitant increase in the quantity of data collected poses new logistical challenges in keeping reporting turnover within an acceptable timescale without undermining the quality of interpretations produced. While there has been some success in addressing these challenges by restructuring internal reporting workflows and by improving collaborative multi-interpreter environments (Harris and Pope-Carter, 2019), large datasets encompassing multiple square-kilometres of readings remain challenging for entirely manual interpretation. The response of Magnitude Surveys to this challenge has been, in part, to explore the use of convolutional neural networks (CNN) for the detection of anomalies in geophysical data, producing outputs then intended for secondary archaeological classification performed by human specialists.

The aim of this study is to assess the possibility of reliably detecting archaeological features in gradiometer data using an approach based on semantic segmentation, and the feasibility of this approach for commercial use. This research project is ongoing, but this paper presents some promising early results. Some of the broad questions that this project aims to address are:

How the quantity and quality of the data affects the development of CNN, and where is this affected specifically by the nature of geophysical data?

What types of network architectures and hyper parameter choices are particularly suited to detecting anomalies in magnetometer data?

How the development of a natively archaeological CNN, trained exclusively on archaeological geophysical data, may improve the algorithm's robustness in detecting anomalies of potentially archaeological nature in comparison with a transfer-learned network?

Background

Manual classification of geophysical data is a labour-intensive task that requires specialist training. Research into improving methods of classifying geophysical data have focused on themes as diverse as the statistical characterisation of noise in order to assist with interpretation of anomalies (e.g. Schmidt et al., 2020), to automating classification of anomalies through the use of object-orientated approaches based on multi-scalar data-segmentation of observed values within magnetic datasets (e.g. Pregesbauer et al., 2014). One of the issues with using only observed geophysical values to classify anomalies is that it requires those of interest to be clearly and quantitatively differentiated from the background and any other interference or noise. While this may be possible on certain geologies, and with certain feature-types, these "ideal" circumstances cannot be guaranteed, particularly where survey is being undertaken as part of developer-led site investigations.

The use of CNN addresses some of the issues which remain with the use of other approaches and algorithms, particularly in dealing with large variety of geologies and soil conditions that would otherwise require manual site-by-site pre-processing of the data to improve feature contrast. CNN have seen a considerable amount of progress over the last two decades and there have been some promising applications in archaeological geophysics: Green and Cheetham (2019) applied the ResNet152 and Google's Inception architectures to successfully detect the presence of Irish medieval graves in GPR B-scan data. In a similar vein, Verdonck (2019) leveraged Faster R-CNN to detect the location of hyperbolas within GPR profiles. Lastly, Küçükdemirci and Sarris (2019) adapted Ronneberger et al.'s (2015) Unet architecture to detect anomalies in GPR time slices. In the wider field of remote sensing there have been numerous applications of CNNs, most numerously so on LiDAR data, using a variety of architectures including, amongst others, ResNet (Trier et al., 2018), Faster R-CNN (Verschoof-van der Vaart and Lambers, 2019) and VGG-19 (Somrak et al., 2020). Each of the above address specific challenges and research questions and all report success metrics in the form of F1 scores and validation accuracy, amongst others.

One of the advantages of CNN is the availability of transfer learning: models can be pre-trained on large open datasets such as the ImageNet library, which reduce the quantity of archaeological data required by pre-training a network on larger non-archaeological datasets. This pre-training allows for the application of CNN to the smaller datasets, which are more common in archaeology, and speeds up the process as the network is already partly trained to some degree of accuracy before it sees the archaeological dataset. Pre-training is not without drawbacks however, as the nature of the data in libraries such as ImageNet can prove too divergent from archaeological data, both in terms of data-formatting as well as complexity and distinctness, which can lead to decreased model performance (Trier et al., 2018, p. 227; Verschoof-van der Vaart and Lambers, 2019, p. 38). The authors would therefore expect networks trained solely on archaeological data to be more robust in their predictions. Conversely, the process of training a CNN on the above-mentioned architectures can be time-consuming and resource-intensive, hence this project also aims to investigate whether significant improvements can be made in this manner with minimal input costs in time and effort. While this project has been driven by commercial imperatives, its potential outcomes and applications would be equally applicable within a purely academic context as time- and financial-constraints increase.

Semantic segmentation is a subfield of CNN applications focusing on the pixelwise classification of input images. Segmentation is of specific interest as it allows the identification of the shape of a target feature within an image (e.g. Küçükdemirci and Sarris, 2019), as opposed to classifying images (e.g. Somrak et al., 2020) or detecting the location of a predetermined feature within an image (e.g. Verdonck, 2019). The architectures required for this task involve some additional steps following the classic series of convolutions native to the CNN family, including some form of up-sampling to return the output to the same size as the network input. The network architectures investigated in this paper are based on variations of those introduced by Shelhamer et al. (2016) and Ronneberger et al. (2015) which both employ up-sampling to produce output labels with the same dimensions as the given inputs.

Methodology

Datasets

For this pilot study, a small corpus of geophysically detected ring ditches and larger circular anomalies was chosen as a dataset. These types of anomalies were selected for having distinct, recognisable features, while also being morphologically more complex than simple linear, or point, anomalies. The dataset was comprised of 150 such features located across the UK, all of which were discovered between 2016 and 2020 by Magnitude Surveys (MS) across a representative sample of commercial archaeological investigations. Collection of the data thus varied in terms of scale, survey conditions, and geological backgrounds, amongst other factors. Broad natural anomalies or anthropogenic activities in the background, such as modern manuring practices, can further complicate the data and reduce the likelihood of features of interest being detected by machine algorithms. Data processing has been consistent across all sites and follows MS' standard processing workflow (Pope-Carter et al., 2017).

Only ring ditches that could confidently be identified as such were included in this dataset, accounting for the relatively small number compared to larger image datasets such as the above-mentioned ImageNet.

A centre point was manually located and applied to each anomaly. The data, stored in MS' in-house archive, was located using these points, which comprised gradiometer data minimally processed in accordance with standards established by Historic England for 'raw or minimally processed data' (David et al., 2008, p. 11), and in line with EAC guidelines (Schmidt et al., 2015, p. 16). Unfortunately, the authors were not able to use true values in this study, as the Keras library used to create the models had difficulties processing the ASCII grids produced by MS. Instead, geotiffed greyscales clipped to a range of -1 to 2 nT were used as data inputs. The labels for each feature comprised of the original interpretations generated manually by MS staff during the reporting process, and stored as polygons in a PostGIS database.

None of the original interpretations were modified, nor were the gradients submitted to any further processing. This approach was taken in order to assess whether this methodology would be feasible with as minimal modification of the input datasets as possible. Although the magnetic data might have benefited from additional processing to enhance contrast and emphasise the target features, this was deliberately omitted due to the high variability within the dataset, and to maintain a consistent baseline against which to assess the efficacy of the methodology. Variability in the dataset was caused by the many factors which can affect magnetic data, such as geology and soils, agriculture, and magnetic interference from modern features. Any pre-processing would therefore also have been necessarily undertaken on a site-by-site basis, a time intensive process, which would also have worked against the premise of this feasibility study.

During the course of this study, the authors created two datasets based on the same input data. In a first run at the start of 2020, the tests were conducted on the polygon source labels including both the ring ditches and any surrounding archaeology, whether the latter could be associated with the ditch or not. This approach presented the least expenditure of effort in the preparation of the data. Following initial results with unstable training and low accuracy predictions, however, a second set of experiments were run on the same dataset, but this time only the polygons describing the actual ring ditches were incorporated. In both cases, the original magnetic gradients were used without any modification.

Pre-Processing

The label polygons were rasterised into 244 × 244 pixel PNGs centred around the manually generated feature centre-points. These labels were classified into three categories – ‘no feature’ where there were no anomalies present, ‘feature’ where there was an anomaly present, and ‘out-of-bounds’ where the gradient included an area of nodata values. The latter was included as some early test runs indicated a tendency to categorise nodata areas as archaeological features. Similarly, the gradients were clipped to the same size – for most gradients included in this survey, this was equivalent to a radius of ca. 25 m at 0.125 m/px, although for a few older datasets collected at 0.25m/px this equated to double the size. The resulting data and label pairs were then randomly sampled into training, validation, and prediction sets at a ratio of 60 %, 30 % and 10 % respectively, or 90 training, 45 validation, and 15 testing image pairs.

Machine Learning

The authors decided on two target architectures for this pilot study: Unet by Ronnenberger et al. (2015) named after their characteristic symmetrical convolutional and up-sampling paths, which was designed specifically for semantic segmentation tasks. This network was discussed by the authors as being particularly advantageous for small datasets (Ronneberger et al., 2015, p. 235), which seemed perfect for an archaeological application and previously has been successfully applied to GPR time-slices in a very similar problem set by Küçükdemirci and Sarris (2019). The second network, ResUNet was developed by Diakogiannis et al. (2020) and expands on the Unet architecture by adding residual skips at each layer to counteract the issue of vanishing gradients which can occur with particularly deep networks. The authors hoped this would allow for developing deeper and more complex networks.

As neither of these networks were published in Python, the authors’ programming language of choice, both these networks were recreated by the authors using Python’s Keras library based on details given in their respective publications. A series of experiments were conducted through parameter exploration in order to tune the hyperparameters for the neural network. The parameters in question are described in Table 1 below.

Table 1. List of parameters explored in this study and their descriptions.

Parameter	Description
Batch Size	Number of image + label pairs processed in a batch, before weights are adjusted within an epoch
Number of Filters	Number of filters added per layer of the network; filters increased by a factor of two per layer, e.g. if the first layer had 8, the second would have 16, then 32 filters and so on
Network Depth	Number of layers within the network
Learning Rate	Rate at which parameters are tuned in order to minimise loss
Loss Function	Function to calculate the loss, which is minimised during training to improve network performance

Training was performed on two NVIDIA RTX 2060S with 8 GB of memory each. Each training iteration lasted 100 epochs, unless no convergence or over-fitting was detected. During each processing run, input parameters as well as the state of machine learning software, represented by git hashes, were stored alongside the outputs in order to enable replication of the results at a later date should this prove necessary.

Metrics

Conventionally, accuracy in Keras is given as a percentage of pixels correctly predicted as belonging to a class, where 1.0 indicates a perfect match. The authors found that the models had a tendency to over-predict pixels as background due an imbalance between background and archaeology in the data, which a simple percentage metric cannot convey. Instead, the authors prefer to use mean Intersection over Union (mIoU), a metric commonly used in semantic segmentation (cf. Ronneberger et al., 2015, Shelhamer et al., 2016), which ranges from 0, no match, to 1.0, perfect match. This metric calculates the number of correctly predicted pixels, the intersection between prediction (P) and ground truth (T), divided by the difference between the sum of all pixels in the prediction and ground truth and the intersection. For multiple classes, the metric is calculated for each category and then averaged.

$$IoU = \frac{|T| \cap |P|}{|T| + |P| - |T| \cap |P|}$$

Results

The initial experiments using the first dataset based on a simple rasterised clip of MS’ interpretation achieved only moderate results of 0.494 mIoU. This prompted the authors to refine the dataset as described above, and to increase the number of inputs via augmentation. This second round of experiments achieved much better results (Table 2) with the highest recorded accuracy rising to 0.703, achieved by a ResUnet model, while the Unet architecture achieved an mIoU of 0.676. Both these results were achieved under the same parameters detailed in Table 3.

Table 2. Results in mIoU achieved by both Unet and ResUnet architectures after training for 100 epochs on either dataset under the same parameters (see Table 3)

Architecture	Dataset 1 (150 Ring Ditches)	Dataset 2 (150 Ring Ditches + 300 Augmentations)
Unet	0.494	0.676
ResUnet	0.484	0.703

Table 3. Hyperparameters used to achieve the results presented in Table 2.

Parameter	Description
Batch Size	2
Number of Filters	16, 32, 64, 128, 254
Network Depth	5
Learning Rate	0.0001
Loss Function	Sparse categorical cross-entropy

One large drawback of the above experimental setup, which became apparent during training, was that the dimensions of the input data resulted in a significant number of parameters (13M+), effectively requiring more RAM than was available on the two graphics cards which had been allocated for training. This lack of capacity caused restrictions on the number of filters and the depth of any network, not to mention ruling out any more complex architecture. By setting a very low batch size, at 2 images per batch, – which in Keras controls how much data is loaded into RAM at any given time – the authors were able to push the remaining parameters, and those described in Table 3 performed the most consistently.

Another, albeit minor, issue encountered, was that only the pre-defined loss functions would produce good results. The authors experimented with variants of loss functions based on mIoU as well as weighted loss functions, however all either performed poorly or did not converge at all. The authors believe this however, to be an implementation issue which can be fixed in the future. That being said, sparse categorical cross entropy which is implemented in Keras seemed to perform well enough under the conditions of the test. Binary cross entropy unfortunately was not an option due to the multi-categorical nature of the labels.

From a visual perspective, the models seemed to perform particularly well in high contrast scenarios, such as in Figure 1, where both Unet (Fig. 1, bottom left) and ResUnet (Fig. 1, bottom right) very closely matched the target label (Fig. 1, top right). The authors noticed that in some earlier experiments the networks had a tendency to fixate on strongly positive features (intense black) over morphological indicators.

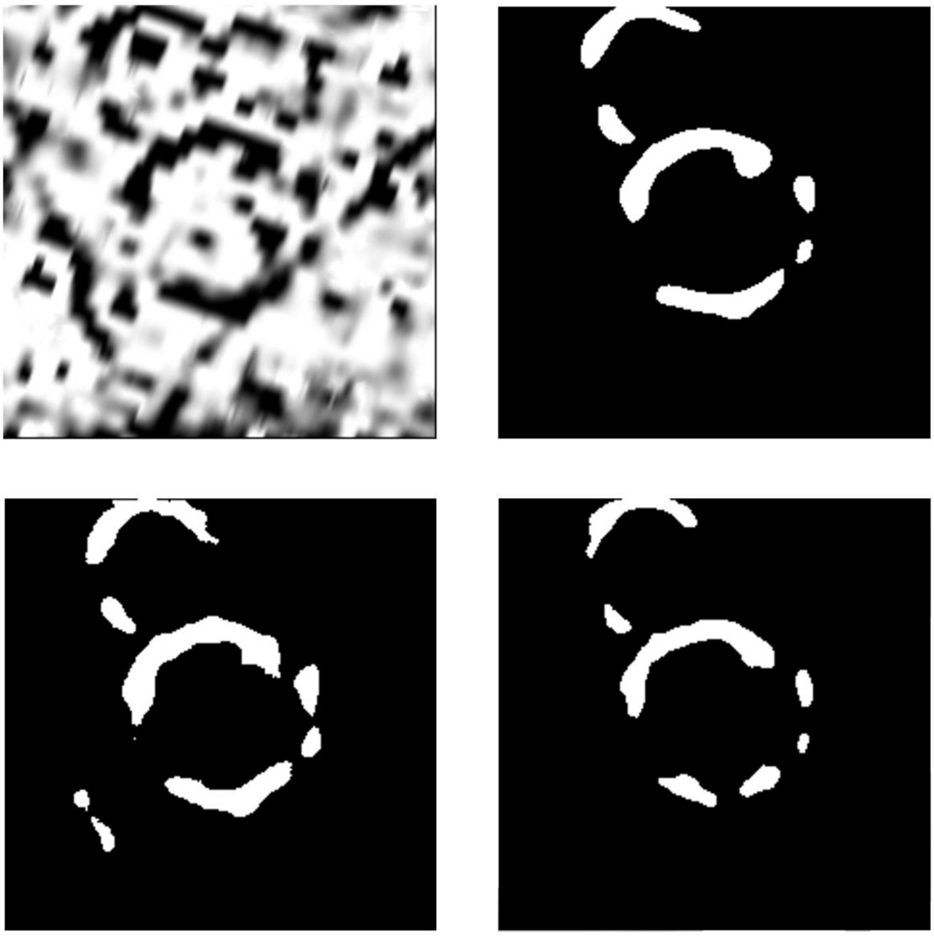

Fig. 1. A previously unseen gradient (top left) with positive readings in black and negative readings in white ranging from -1 to 2 nT. The predictions by the Unet (bottom left) and ResUnet (bottom right) models after 100 epochs of training (cf. Table 2 for parameters) both matched quite closely to the ground truth label (top right) despite the noisy background. (© Magnitude Surveys Ltd 2022)

Where the target feature was quite ephemeral in nature or obscured by surrounding anomalies, unsurprisingly both models struggled. Figure 2 highlights one such example; in this case, the Unet performed much better than the ResUnet, the latter of which picked up some of the positive linear anomalies cutting through this ring ditch.

Discussion

Overall, the authors believe that the results so far have been promising, and demonstrate the potential in the application of semantic segmentation within commercial geophysics. This was achieved with very low effort using existing datasets and no additional processing of the magnetometer data, as well as being based solely on magnetometer data without any prior pre-training on larger image datasets such as ImageNet. There are however a number of areas that will likely result in improvement in the overall performance of the model.

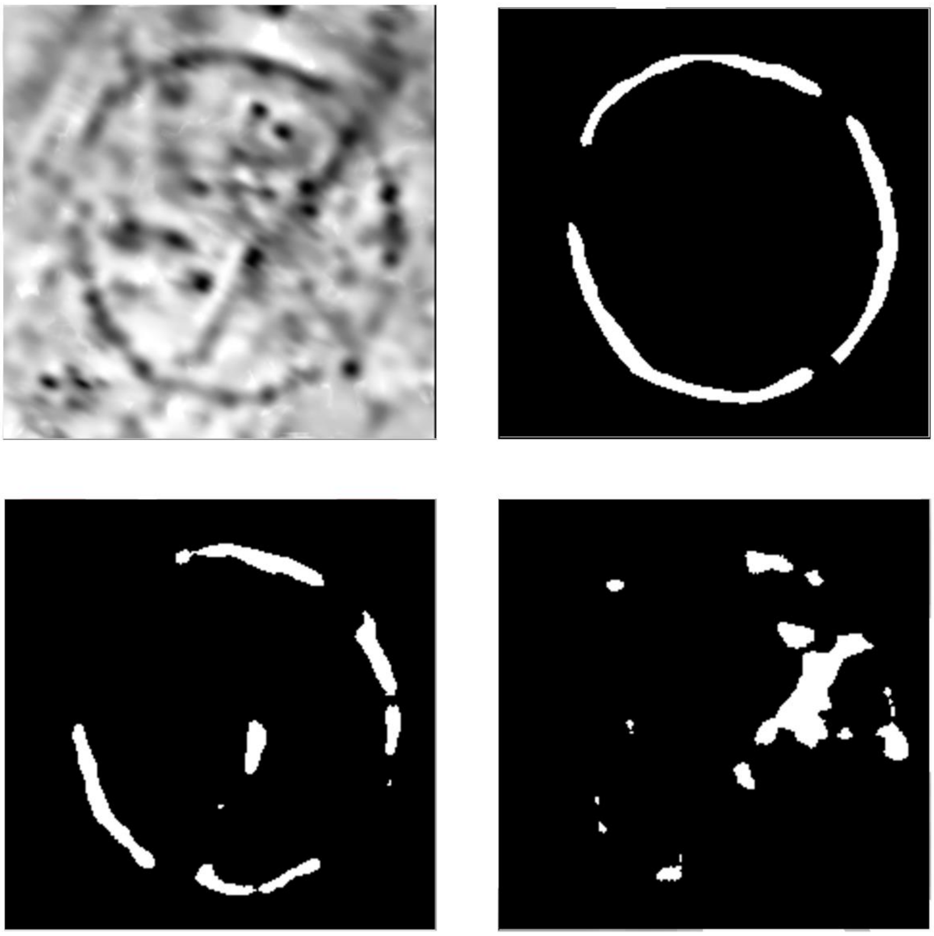

Fig. 2. A previously unseen gradient (top left) and ground truth labels (top right) with predictions by Unet (bottom left) and ResUnet (bottom right) models after 100 epochs of training (cf. Table 2 for parameters). Both models struggled on more ephemeral targets such as this one, with the Unet in this case performing much better at detecting the ring ditch. The ResUnet seems to have been confused by the agricultural feature cutting through the ring ditch.(© Magnitude Surveys Ltd 2022)

The performance boost achieved by moving from the first to the second dataset highlighted the importance of selecting good training data, as well as demonstrating the usefulness of data augmentation. Only zoom and pan augmentations were used in this case, however it might be possible to use rotation and flipping, although here the question presents itself whether these are relevant to magnetic data. Orientation is important for the human interpretation of some archaeological features as well as some magnetic features, although it remains to be seen whether this is the case for automatic identification.

While ring ditches are very distinct features found in archaeological geophysics, the obvious next step will be to test different and more numerous features. Linear agricultural features such as ridge and furrow, or historic field boundaries are much more prevalent across the UK and would provide a very large potential dataset with greater morphological diversity. These are particularly interesting targets for automatic identification, as their manual digitisation can be particularly labour intensive.

In addition to increasing the size of the geophysical training data, picking a larger dataset to pre-train the network and/or using transfer learning on a dataset more akin to geophysical data could also provide measurable improvements to model performance. Pre-training on ImageNet was avoided in this study given the concerns raised above, however there are other datasets more comparable to magnetometer data that could potentially be used for pre-training. Gallwey et al. (2010) explored lunar LiDAR data as a potential such pre-training dataset with promising initial results on the Arran dataset. It would be interesting to investigate whether a similar approach would lead to a performance gain here.

The results have also defined some clear limitations in the above experimental setup. The size of the inputs unfortunately limited the parameter choices available in this pilot study. Even with two graphics cards, the hard limit in terms of model complexity was set by the memory of a single graphics unit, at least for the Keras library used in this study. Reducing the size of the images may require some rescaling and thus either loss in area covered or a loss of detail. For the ring ditches in this study, a reduction in size was not possible, as some of the larger examples required a diameter of up to fifty metres. In this case, a loss of detail by scaling down the images to a lower resolution would be required. For linear features such as ridge and furrow, this is not an issue as the images would rarely be able cover the entire feature to begin with.

By reducing the size of the inputs and freeing up more memory, or as the available computing power increases, it will also be possible to increase the batch size. During training, the authors found that having a small batch size with a highly variable training dataset such as this one can lead to very erratic development. Given a bigger batch size, training might be slower, however the authors expect that convergence would be steadier. Moreover, to speed up training again, it would be possible to increase the learning rate.

Conclusion

This paper has shown that automatic identification of archaeological features, specifically ring ditches, found in magnetometer data is possible and commercially feasible with the input of very little time and effort. The experiments presented in this paper achieved a maximum mIoU of 0.703 using a ResUnet neural network. These results were achieved by training the neural network on magnetometer data and pre-existing labels from MS' archives, without using pre-trained weights.

In the discussion above the authors have highlighted several areas of improvements which may yield higher accuracy. Future work will focus on improving the performance of the model, as well as the implementation of these models into MS' magnetometer processing workflow pipeline. The authors' aim is to implement a robust system whereby data are automatically streamed onto in-house servers where basic data-processing and the extraction of features can be undertaken in a matter of minutes, providing specialists more time to spend on qualitative tasks such as interpretation and analysis.

One major issue in archaeology, however, remains the option to quantitatively compare the performance of different approaches against a common benchmark. To that extent, Kramer (2021) has recently published the Arran benchmark dataset based on data collected from the Isle of Arran, Scotland, during the Rapid Archaeology Mapping Programme (RAMP) (Banaszek et al., 2018). This first of its kind benchmark within archaeology may enable a fairer comparison of archaeological CNN models and further accelerate prototyping of new methodologies for archaeological purposes.

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Session:
Architecture and Heritage

Wolfgang BÖRNER

‘Kyiv River Gate’ is a new formula for revitalizing the archaeological heritage in the historical core of the ancient city

Excavations conducted in 2014–2018 on Poshtova Square in Kyiv

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Abstract: Excavations conducted in 2014–2018 by the Center of Archeology of Kyiv of the National Academy of Sciences of Ukraine on Poshtova Square in Kyiv prove that among the archaeological territories of the city there are those where it is possible to observe how the city can remain unchanged in its planning structure for many centuries. These include the place where the modern Poshtova Square is located, which stands out in the relatively flat relief of the Lower Town – Podil. The purpose of this study is collective and multitasking research, which allows to solve a number of pressing issues: preservation of unique archaeological finds, creation of a museum complex directly on the site of archaeological excavations. ‘Kyiv River Gate’ is a fundamental change in the attitude to cultural heritage, “resetting” the attitude to cultural values as an invaluable potential for development and popularization the cultural heritage of the archaeological site as the national and world property.

Keywords: *Medieval archaeology—dendrochronology—Kyiv—underground museum—in-situ museum in urban context—public space*

CHNT Reference: Yurchak, I., Yurchak, N., Sahaydak, M., Sahaydak, S., Rutkovska, O., and Biletskyy, V. (2022). ‘Kyiv River Gate is a new formula for revitalizing the archaeological heritage in the historical core of the ancient city’, in Börner, W., Rohland, H., Kral-Börner, C. and Karner, L. (eds.) *Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020*. Heidelberg: Propylaeum.
doi:10.11588/propylaeum.1045.c14484

Archaeology and dendrochronology of the archaeological object ‘Site of the coastal city quarter of medieval Kyiv’ (11–19th centuries)

The area is located at the foot of the macroslope of the Kyiv plateau in the area of its contact with the south-eastern corner of the Podil pseudo-terrace and the Dnieper riverbed. Increase of the sole of the slope occurred sporadically by proluvial deposits. This is evidenced by the presence of an ancient removal cone at the base of the sole of the macroslope, buried under technogenic deposits (Fig. 1).

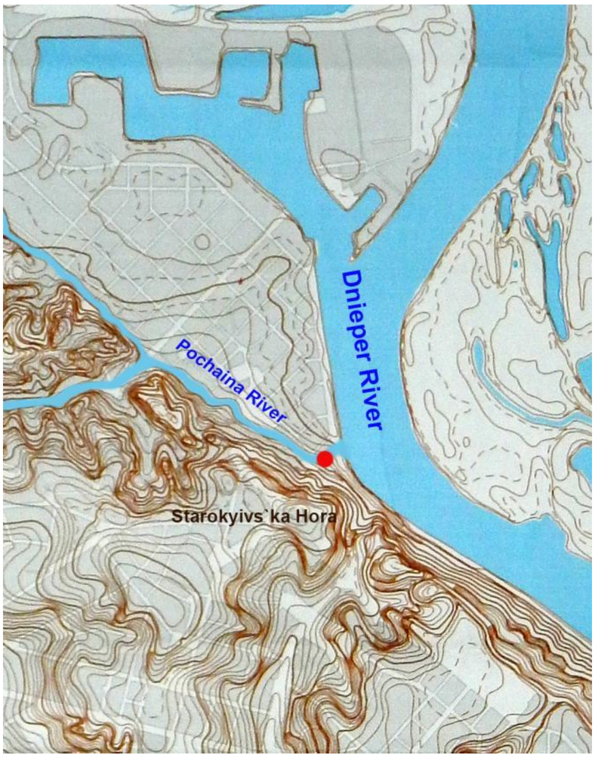


Fig. 1 Relief map of Kyiv-Podil and Kyiv plateau. Place of archeological research of the Poshtova Square, 2014–2017. © Authors.

The location of archaeological complexes testified that from the second half of the 11th century to the end of the 13th century the removal cone "grew" by several meters. The main source of proluvium should be considered Mikhailovsky (Borychiv?) Uzviz – the route of the modern funicular. Obviously, the chronology of the first arrangement of the descent dates back to the 10th century. This fact can be clarified by further excavations as the initial development horizon lies at a mark that lies 4 m below the studied horizon. As a result of archaeological and geomorphological research, we proposed the hypothesis that the chronicle Pochayna river (right bank of the Dnieper) flowed in the 10–11th centuries along the root bank of the Kyiv Mountains, so it is very likely that Podil during this period should look like a floodplain island.

As it turned out, from the second half of the 11th century, when the channel of the ancient Pochayna was already covered with alluvial-proluvial deposits and moved to the northeast, about two hundred meters closer to the main river Dnieper. Here the building is actively beginning to take shape, and its character is somewhat different from the typical manor and yard buildings of Podil. On the one hand, this was because this was the beginning of the planning axis of Podil – the main street, on the other hand, that it belonged to the structure of the port economy of the city. The street continued to operate until the catastrophic fire in Podil in 1811 (Sagaidak, 2018). It was possible to study the traces of the functioning of several city yards, which stretched along the front of the street, separated by a wooden fence made of semi-logs (Fig. 2).

Fig. 2. A, B. View of the fence of the "big yard" of the 11–12th centuries. © Authors.

The dimensions of one of the most researched yards, with an area of 840 sq. m., attract attention, while the maximum size of the Podil yard is considered to be an area of 600 sq. m. [Сергій Тараненко, 2016]. Traces of at least 9 residential, craft and economic complexes, which functioned on this place from the end of the 11th to the beginning of the 19th century, were found on the territory protected by a wooden fence. The active phase of the yard complex is evidenced by the discovery in the filling of Building 1 – lead ingots, weighing a total of 8 kilograms, and in the northern zone – a series of so-called "hanging" seals, dating from the second half of the 11th to the first half of the 12th century (Fig. 3).

Fig. 3 'Hanging' seals 11–12th centuries. © Authors.

The picture of the building and functioning of the yard is complemented by the fact that on one of the horizons of a whole warehouse of building materials – plinth (slab) – flat and wide brick, which was used in stone construction in medieval Rus' in the 12th century. It should be noted that in 2012, the remains of a small wooden Christian church of the 12th century were excavated in the adjacent section of Podil (Тараненко, 2016).

Dendrochronological analysis on the materials of Kyiv-Podil

Archaeological excavations of Poshtova Square have revealed the remains of an important town-planning hub of Kyiv Podil, the complex of which contained the beginning of the main street of the Lower Town, some port buildings with wooden decks and bridges, a monumental, about 10 m long structure, made of oak logs, apparently for transport purposes, an artificial shaft built of kaolin clay on a wooden base, which protected the city from floods and served as a pier.

New materials obtained from the excavations show that for several centuries the lower part of the road (descent), which connected the port zone of Podil with the Upper Town (Mountain), came out on the site adjacent to the studied "big yard".

Archaeological materials that have passed the first stage of scientific processing and determinations, including more than 7 thousand only ceramic products, 1700 fragments of glass products, more than 1 thousand metal objects (special attention should be given to rivets for the sides of ships), anthropological and zoological remains (more than 3.5 thousand units), building materials, industrial waste. A number of wooden structures (wet wood) have been dismantled and will be preserved and used to recreate authentic buildings in the exposition of the future underground archaeological museum. Work has begun to determine the chronology of archaeological sites by a method such as dendrochronology. The dendrochronological scale, developed primarily on the materials of Kyiv-Podil, provides a high degree of reliability in determining the time of construction of wooden structures discovered by excavations.

Laboratory processing and construction of chronology were performed using classical dendrochronological methods (Schweingruber, 1988). Initially, samples were prepared in the laboratory for microscopic determination of wood species, as well as the boundary of annual rings. Measurements of the width of the annual increments of the samples were performed on an instrument with an accuracy of 0.01 mm at 20-fold magnification of the microscope.

During the dendrochronological analysis, wood samples were taken from the paving structure, which made it possible to construct a generalized relative chronological curve with a total duration of 85 years for Object 1. The obtained chronological curve used for cross-comparison with samples taken from Object 1 (Report, 2014–2015). The synchronization gave grounds to claim that both objects were built of wood, which was cut down in the second half of the 17th century.

Another object of dendrochronological dating of the specified period of the archaeological monument was a wooden tub standing in the corner of the building. 10 samples were taken from the boards from which the tub was made. The wood from which the boards were made, as well as previous samples, belongs to the annular deciduous species – oak (Quercus sp.), has traces of machining. The number of annual increments varies, from 98 to 110. The thicknesses of annual increments were measured, as well as similarity coefficients were determined, which made it possible to construct a relative chronology of 150 years (Fig. 4).

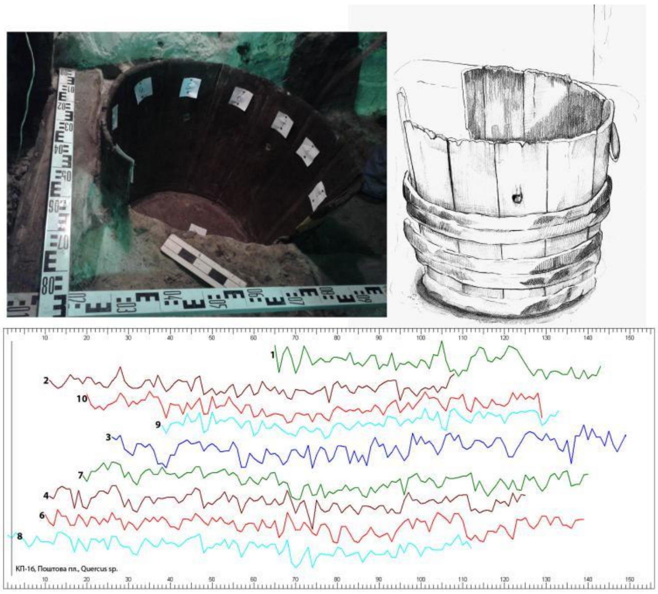


Fig. 4 Graph of annual increments for a series of samples Tub 1. © Authors.

The importance of this place proves the fact that in the study of the estate was discovered a series of so-called “hanging” stamps dating from the second half of 11th to the first half of the 12th century. The attribution of these finds shows that this act material belongs to one of the branches of the Grand Ducal Kyivan dynasty – Monomakhovych.

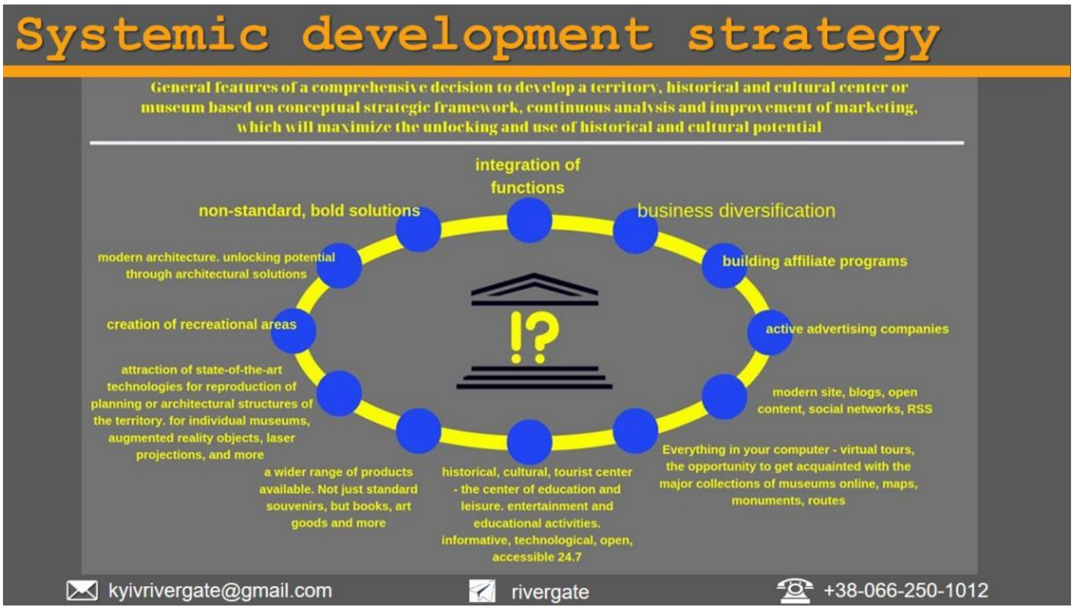
Poshtova Square is starting point in the development of historical and cultural tourist center

The unique monument of archeology and history ‘Site of the coastal city quarter of medieval Kyiv’ (11th–19th centuries) on one of the oldest squares – Poshtova Square has been the object of public resonance for more than two years and the subject of discussions about the creation of modern Archaeological Museum. The monument is a landmark area of about 6,000 m² of a multi-layered complex of remnants of the medieval quarter, with the remains of the planning structure, roads, protective walls, buildings of the estate. Remains of buildings found under the square are built of hardwood and pine wood. At present, the monument has been studied by archaeologists of the Center of Archeology of Kyiv to the level of the period of the end of the 11th–12th centuries (mark +100 according to the Baltic system) and preserves an even older cultural layer about 4–5 m deep.

Already during the research of the monument in 2014–2016, the planning structure discovered by archaeologists, the remains of wooden buildings and the findings of the medieval quarter on the Poshtova Square entered scientific circulation and aroused considerable interest of the international scientific community. However, by the beginning of 2018, the remnants of the quarter were threatened with destruction by many factors, which together opened the possibility for the construction of an underground shopping center.The very idea of protecting the monument and creating a modern museum on it prompted a large community of Kyiv from more than 15 public associations to launch an indefinite peaceful action on June 20, 2018, which continues to this day. On November 23, 2019, the peaceful action was recognized as a record of Ukraine (registration № 33 / 02–20207).

During the peaceful action, the monument gained national status at the initiative of its participants, and at the initiative of V. Biletsky and the support of the National Union of Architects of Ukraine, the first public competition for the best concept of the historical and cultural tourist center ‘Kyiv River Gate’ was held on Poshtova Square. The aim of the competition was to find the best idea for the rehabilitation and development of the cognitive resource of the public space of the square, as an integral part of the center of Kyiv. The competition lasted from November 1, 2018 to July 19, 2019. In conducting the competition according to the rules set by the national legislation of Ukraine, we used an unusual technology – a series of expert discussions on urban, transport, historical, tourist, environmental context and provided a completely independent online evaluation for the jury. The winners of the competition were selected by a highly professional jury, and the best competition proposals were the concepts of professional teams of Kyiv architect Lyudmila Bazhenova and Igor Yurchak’s Creative Studio.

The results of the competition, as well as the idea of creating a historical and cultural tourist center ‘Kyiv River Gate’ combined with the marketing concept of V. Biletsky on the development of the territory taking into account the potential of Old Podil, State Historical and Architectural Reserve “Ancient Kyiv” and other areas of Kyiv were repeatedly presented both in the National Union of Architects of Ukraine and in the Kyiv City Council, as well as at the International Architectural Biennale in Krakow MBA Krakow 2019 in the section of concepts. The purpose of the concept of the Center ‘Kyiv River Gate’ is to change the attitude to cultural heritage as a ballast, to reveal its potential, to form a tourist network and to ensure sustainable development with efficient and balanced use of monuments of the oldest urban area of 175 hectares. After all, it is not enough just to create a museum on an archaeological site, it is important that it operates in the system of the tourist network.The concept is aimed at the development of historical and cultural centers as a significant resource for the development of society, culture, tourism, economy and defines their priorities. The foundation and basis of sustainable development of the historical and cultural center is a commercial activity with a wide range of functionality (Fig. 5).



Systemic development strategy

General features of a comprehensive decision to develop a territory, historical and cultural center or museum based on conceptual strategic framework, continuous analysis and improvement of marketing, which will maximize the unlocking and use of historical and cultural potential

integration of functions

non-standard, bold solutions

business diversification

modern architecture. unlocking potential through architectural solutions

building affiliate programs

creation of recreational areas

active advertising companies

attraction of state-of-the-art technologies for reproduction of planning or architectural structures of the territory. for individual museums, augmented reality objects, laser projections, and more

modern site, blogs, open content, social networks, RSS

a wider range of products available. Not just standard souvenirs, but books, art goods and more

historical, cultural, tourist center - the center of education and leisure. entertainment and educational activities. informative, technological, open, accessible 24.7

Everything in your computer - virtual tours, the opportunity to get acquainted with the major collections of museums online, maps, monuments, routes

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Fig. 5 Concept of development of historical and cultural centers ‘Kyiv River Gate’. © Authors.

An equally important component in the preservation, preparation for the exhibition of archeological monuments of the 11th–19th centuries on the Poshtova Square is the need to involve the maximum range of digital research technologies for a detailed assessment of possible options and volumes of conservation and exhibition. We insist on the maximum use of non-destructive research technologies, as the monument has, according to preliminary findings, another 4–5 m of cultural layer, which contains the remains of the planning structure, buildings, individual finds of older times. Therefore, the facility needs the most thorough non-destructive testing with in-situ conservation. Full and detailed geo-radar scanning with detailed interpretation of results, laser scanning and 3D modeling, the most detailed photo and video capture of layered disclosure with the creation of an augmented reality channel, conservation, attribution and preservation for future exposure of existing stratigraphic profiles should be the basis of further scientific programs research.

Igor Yurchak' Creative Studio's Concept of the organization of the public space of Poshtova Square presents most comprehensive urban analysis of the location of the object in the body of the city as a result of detailed analysis the perception, accessibility, functional zoning, semantics and physical state of Poshtova Square, and gives the appropriate town-planning decision (Fig. 6).

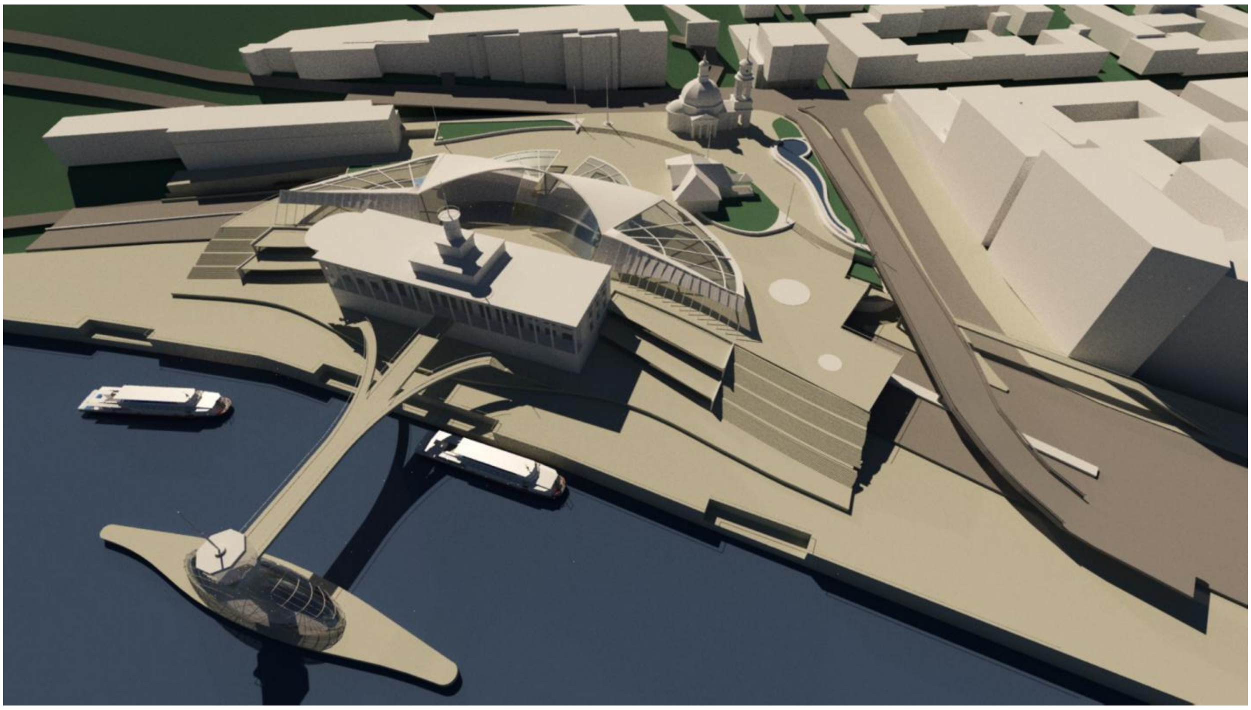

Fig. 6. View of the reconstructed Post Square according to the town-planning concept. © Igor Yurchak's Creative Studio.

Urban concept of the organization of the public space of Poshtova Square

Transport hubs and transits is a main city-planning problem in the space of the Poshtova Square. We propose to lay a number of routes of railway, surface and overground transport in order to arrange a comfortable stay on the Poshtova Square, coverage in a single picture of tourist tricks along the Dnieper, maximum restoration of today's isolated space of the square with its historical connections on the Podil completeness and integrity of the image of the Podil of Kyiv, most ancient part of Kyiv (Fig. 7). In order to arrange a comfortable space of Poshtova Square, to include it in the network of tourist accents along the Dnieper, to maximize the connection of the isolated space of the square with its historical connections at Podil and to form the integrity of the image of Podil on the map of Kyiv:

- Walking tram, to the south, along the "Arch of History" (9 stops), along the cliff above the Dnieper: past the memorial to Magdeburg law, the government quarter, past Askold's Tomb, the Park of Glory, steel sculpture Motherland, through the possession of Kyiv-Pecher Lavra, through the Dnieper Navodnytsky Park, past the Vydubychi Monastery and to the Botanical

Garden, with the possibility at the end of the route to change to a monorail for a walk to the Botanical Garden. The total length of the route "Arc History" is 7 km

- Carriage, to the north, along the small ring of Podil, the total length of the route is 2.8 km
- River tram along the Dnieper, to the south, from the legendary Prytyka to Navodnytsky Park, the total length of the river route – 5.5 km

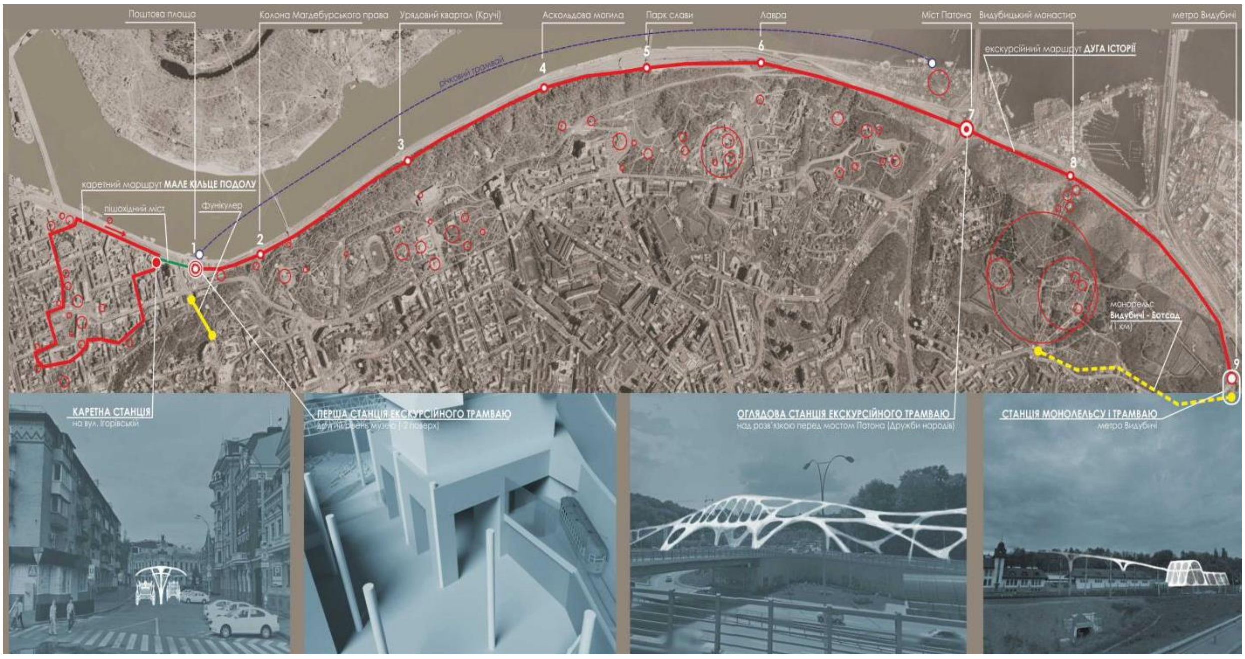

Fig. 7. Scheme of excursion routes adjacent to the Poshtova Square. © Igor Yurchak's Creative Studio.

Underground museum

Poshtova Square is a place where fateful events for Rus' took place, where the chronicle Pochayna River flowed into the Dnieper River, where Ruchai River met the waters of the main ar-tery of the city from the slopes, where were built Prytyka (pier) and Khreschatyk Gate (customs). In addition, archeology reveals through the relatively shallow layers of coastal sediments the remains of buildings, courtyards and shops, which periodically together with climatic fluctuations, hydrological, tectonic and geological changes and anthropological influence, present true demonstration of history. Therefore, the arrangement of the underground museum of Kyiv history with in-situ conservation has become an urgent need given not only the majesty of events, but also the uniqueness of conservation the cultural layers of different historical periods as an example of integration strategies for archaeological heritage in urban context. The Underground Museum on Poshtova Square is a three-level space, which divided into three functional zones:

- Communication and transit zone, which forms the flow of visitors and their distribution in accordance with the program of stay in the museum (through all 3 levels)
- The zone of historical reconstruction, covering all three levels of the museum, two of which are in-situ conservation of archaeological finds at the site of the historical building (quarter) of the corresponding layer. Thus, the exposition of the museum will chronologically demonstrate 2 different cultural layers with the most preserved artifacts and the uniqueness of their occurrence.

- Interactive zone of the multimedia show – through -1, -2, -3 levels, where the history of Poshtova Square is presented using a creative digital product that creates a deep immersive effect (with 3D mapping, panoramic shooting, animation, acoustic and special effects). In addition, the design features provide natural lighting of all levels of the interactive zone through the transparent bottom of the Perun Fountain, which will add depth and effect.
- Underground exposition mine 'Geology of Podil' is an excursion route in a glass elevator with the ability to view the geological layers of Poshtova Square through all 3 levels

Exposition zoning

Level -1 provides a museum space with a children's play area Kyiv Grad, an area of innovative education for groups of preschoolers and schoolchildren (3–5, 6–9, 10–13 years) and locations of partial review of the expositions of lower levels (Fig. 8).

1. Entrance distribution group
2. Elevator of the through underground exposition mine 'Geology of Podil'
3. Observation deck of the panoramic layout 'History of Podil' (highest vantage point)
4. Kyiv Grad play area
5. Children's interactive area (halls-transformers for mini-theater, lecture hall and games)
6. In-situ exposition zone of historical reconstruction 'Prehistoric Kyiv' (overview)

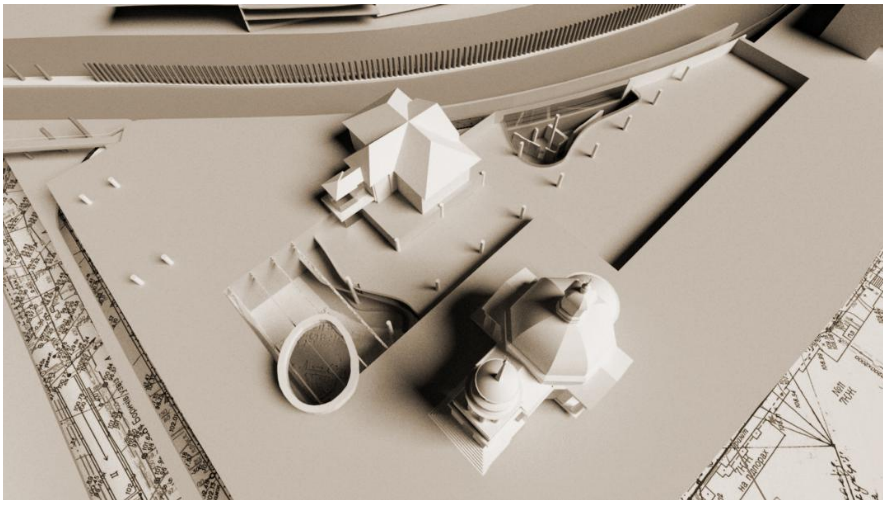

Fig. 8. Exposition zoning, Level -1. © Igor Yurchak's Creative Studio.

Level -2 provides a in-situ museum space with the main exposition of historical reconstruction 'The medieval quarter of the Kyiv Podil in the 15th century' on the site of archeological finds and the area of partial inspection of the exposition of the lower level 'Prehistoric Kyiv' and the excursion tram stop along the 'Arc of History' (Fig. 9).

1. Entrance distribution group in Level -2
2. Elevator of the through underground exposition mine 'Geology of Podil' in Level -2
3. Observation deck of the panoramic layout 'History of Podil' in Level -2

4. The main in-situ exposition of the historical reconstruction ‘The medieval quarter of the Kyiv Podil in the 15th century’.

5. In-situ exposition zone of historical reconstruction ‘Prehistoric Kyiv’ in Level -2

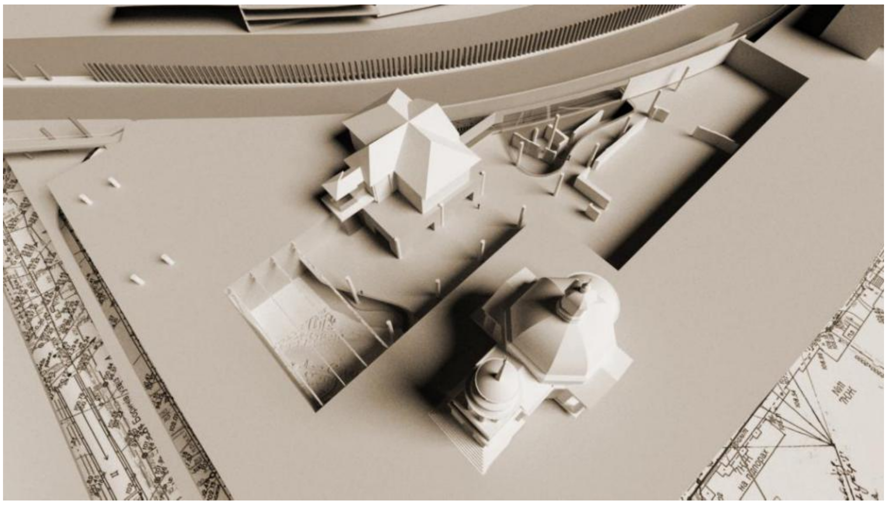

Fig. 9. Exposition zoning, Level -2. © Igor Yurchak’s Creative Studio.

Level -3 provides a museum space with an arranged isolated transparent gallery exit of the subway, which is spatially zoning to 2 independent locations: the exposition of historical reconstruction ‘Prehistoric Kyiv’ on the site of authentic archaeological finds and the interactive area of the multimedia show from prehistoric times to the present (Fig. 10).

1. Entrance distribution group in Level -3
2. Elevator of the through underground exposition mine ‘Geology of Podil’ in Level -3
3. Isolated gallery exit of the subway
4. Interactive area of the multimedia show ‘History of Podil’ with an amphitheater
5. The main in-situ exposition of the historical reconstruction ‘Prehistoric Kyiv’

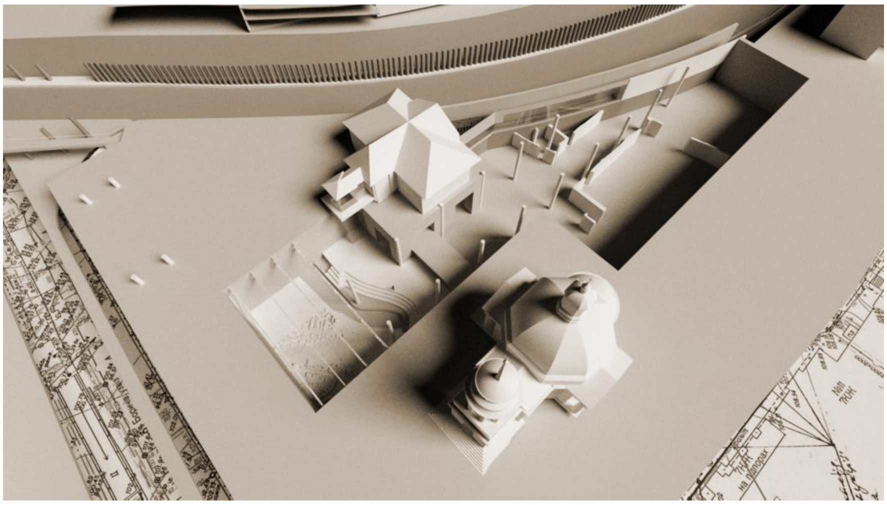

Fig. 10. Exposition zoning, Level -3. © Igor Yurchak’s Creative Studio.

Conflict of Interests Disclosure

The authors declared no conflicts of interest.

Author Contributions

All authors contriubuted equally to the paper.

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Session:
Digital evolutions of the City of Vienna

Franz Xaver PFAFFENBICHLER | Lothar EYSN

Call

Franz Xaver PFAFFENBICHLER, City of Vienna, Austria
Lothar EYSN, City of Vienna, Austria

Keywords: *Smart City Vienna—ViennaGIS—Digital City Map—Digital Twin—Wien gibt Raum—Open Data—WienBot—Kappazunder—Artificial Intelligence*

The City of Vienna and its departments use digital data, tools and artificial intelligence as part of a common digitization strategy for applications to conserve resources and maintain the high quality of life. Using cutting edge technologies and analytical methods, the data are processed to support governmental decisions and may form the basis of a future Digital Twin.

Due to the setup and use of novel digital tools, Vienna is a pioneer in the field of Open Government and enables participation as well as transparent processes. Vienna's strong Open Government Data (OGD) directive means, that the city makes figures and data available for public and free use. Hundreds of data records provide detailed information about one-way streets, real-time information of the public transport, historical aerial images, archaeological data, measurement data for air pollutants or WLAN locations, to name just a few areas.

One example beyond others is the program "Wien gibt Raum" and it's related concept for an innovative management of a major city's public space using a large scale mobile mapping campaign. This campaign is carried out by the Department of Surveying and Mapping, and deals with the acquisition of high quality geodata (georeferenced digital images and 3D data) within the entire city. These data are anonymized and made available to the departments of the City of Vienna in a web-based image data service (Kappazunder). Based on these data, existing objects within the public space can be inspected or surveyed and may be analysed using artificial intelligence. In the future, these data may also be a sufficient input to feed the idea of a Digital Twin. The City of Vienna takes over in many areas of ICT the pioneer task for the future.

In this session we will show some examples of high-tech solutions generated by the City of Vienna and also our new Digital City Map.

Digital geoTwin Vienna

What does *geo* with the Twin?

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Keywords: *Semantic 3D City Model—City Information Modelling—Cim—3D Gis—Digital Twin—Digital Geotwin*

CHNT Reference: Lehner, H. and Kordasch, S. L. (2022). ‘Digital geoTwin Vienna. What does *geo* with the Twin?’, in Börner, W., Rohland, H., Kral-Börner, C. and Karner, L. (eds.) *Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020*. Heidelberg: Propylaeum.
doi:10.11588/propylaeum.1045.c14486

Virtual 3D city models usually evolved from other geodata sets and were not set up from scratch. As traditional geodata used to be only 2D and 2.5D for a long time, 3D city models started naturally with 3D building models. On the one hand, this has a technical aspect, because buildings, especially when being modelled in a higher level of detail, can be described neither in 2D nor in 2.5D. On the other hand, this is because buildings form the identity of a city. This can clearly be seen when looking at the sights of a city, which are usually historic or modern buildings, such as cathedrals, palaces, skyscrapers, etc. In many cases, the 3D building models themselves were called 3D city model, because they are so essential for a virtual 3D city. A common way to create a 3D city model beyond the buildings is to combine them with 2D (i.e. city map) and 2.5D (i.e. digital terrain model) GIS data sets. In case the models are used for visualization purposes only, the city map is normally used in a raster format as texture on the terrain model. In case semantic 3D models are aimed for in order to use them for analysis, 2D city map vector data are raised, e.g. to a terrain model or a 3D point cloud. Continuative steps to enrich the virtual scene are often adding 3D bridge models or vegetation created by a set of template tree models and point-based tree information with height and tree top diameter as attributes to the point information. Problems usually occur due to temporal incoherence of the data sets. While for visualization purposes, these problems might be neglectable, they have to be tackled in case the resulting 3D city model should serve as basis for a city information model. In this contribution, a new strategy in producing the 3D city model as well as other geodata products of Vienna, which completely rethinks and reverses the geodata workflows currently in use, are discussed.[1]

The centre of the strategy is to use the existing three-dimensional surveying and mapping data and potentially further input data to directly model a Digital geoTwin (see Fig. 1)—a virtual, semantic 3D replica of all elements and objects of the city.[2] Digital twins are an upcoming concept of digitizing

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[1] Lehner, H. and Dorffner, L. (2020). ’Digital geoTwin Vienna: Towards a Digital Twin City as Geodata Hub’, *PFG – Journal of Photogrammetry, Remote Sensing and Geoinformation Science* 88, p. 63. doi:10.1007/s41064-020-00101-4.

[2] Lehner, H. and Dorffner, L. (2020). ‘Digital geoTwin Vienna: Towards a Digital Twin City as Geodata Hub’, *PFG – Journal of Photogrammetry, Remote Sensing and Geoinformation Science* 88, p. 63. doi:10.1007/s41064-020-00101-4.

elements, processes and systems of physical entities in order to create living digital simulation models as collaborative platform for many disciplines. The prefix **geo** was integrated in the neologism Digital **geo**Twin to emphasize the focus on the geodetic, geometric aspect of creating semantic geo-objects for a digital twin. This Digital geoTwin should allow to derive other needed GIS data sets from it, which in corollary ensure full temporal and contentual coherence for all derived products.[3]

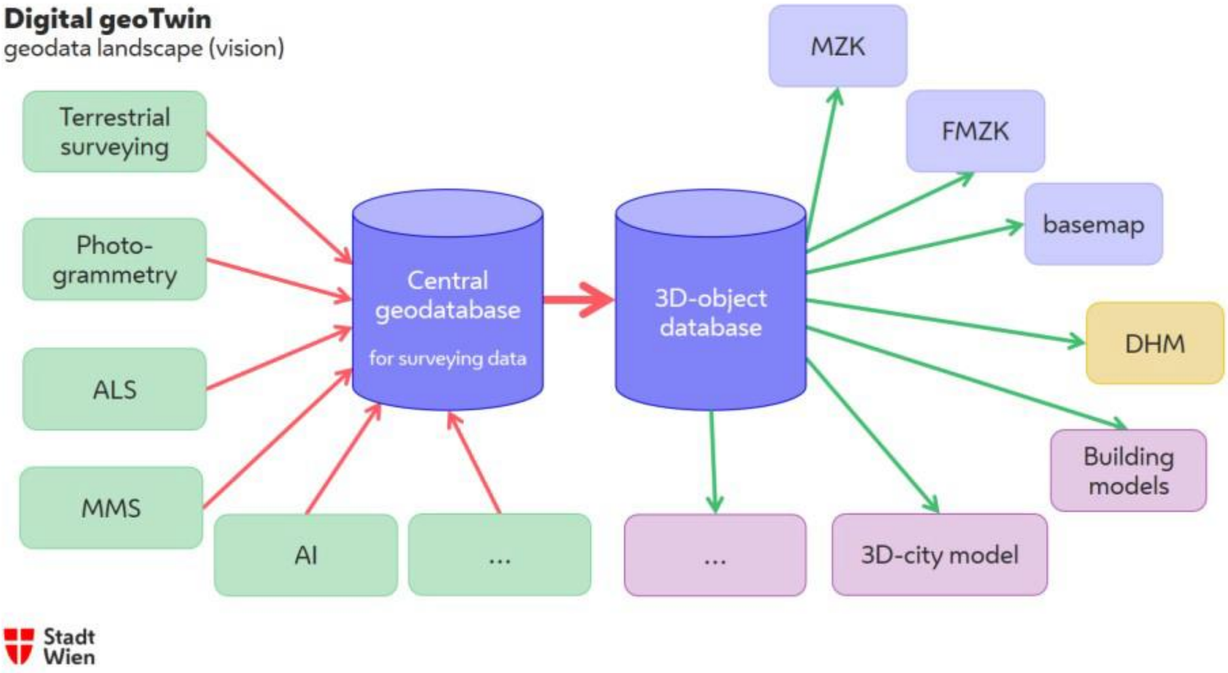

Fig. 1. Geodata landscape (vision) (© City of Vienna, Surveying and Mapping – Department 41)

Fig. 2. Linking of databases (CIM) (© City of Vienna, Surveying and Mapping – Department 41)

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[3] See footnote 2.

To ensure the embedding of the Digital geoTwin in the Digital Twin of the City of Vienna, several use cases were defined within the project. By linking the objects of the Digital geoTwin with further data and information, e.g. census data, socio economic data, energy consumption data, maintenance management data, etc., a city information model can be built up to serve as basis for a living digital twin of Vienna.[4] (see Fig. 2)

The second use case deals with 3D planning data, which is often generated during planning processes. In the course of the process the models are refinded. Thus, the level of detail rises from block models (see Fig. 3), which are used in the early stages of the process, to detailed architectural models. A wide range of data formats might be used in the process and the especially the more detailed 3D-models are often not georeferenced. By storing the data in a central planning database, advantages such as various simulations in advance can be achieved. Furthermore, the integration of planning data into a Digital geoTwin contributes to public relations and citizen participation.

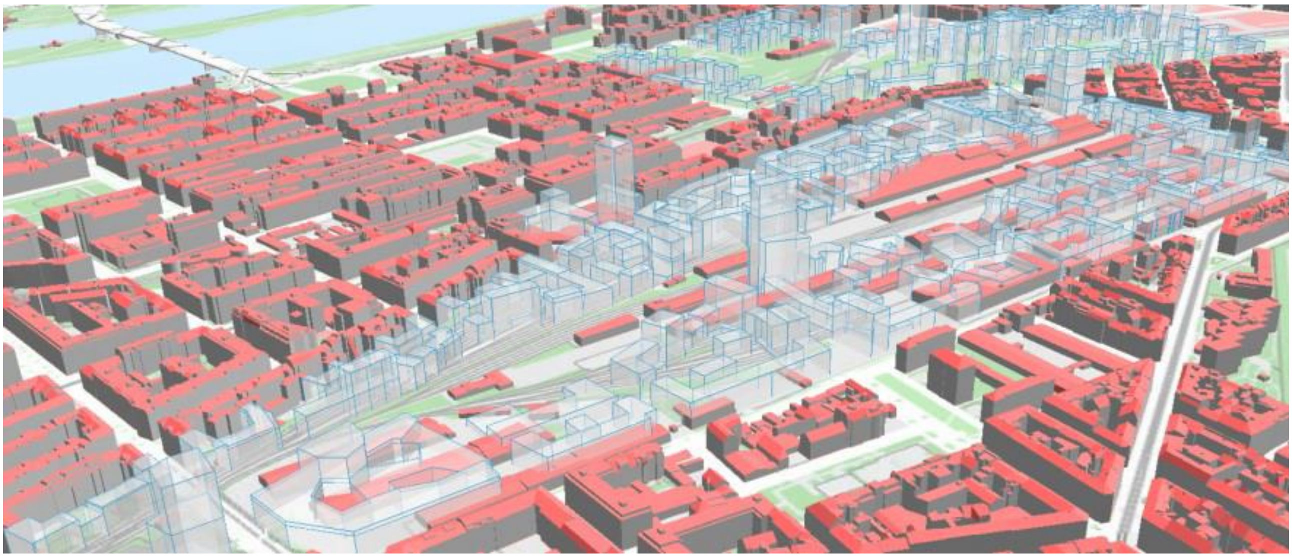
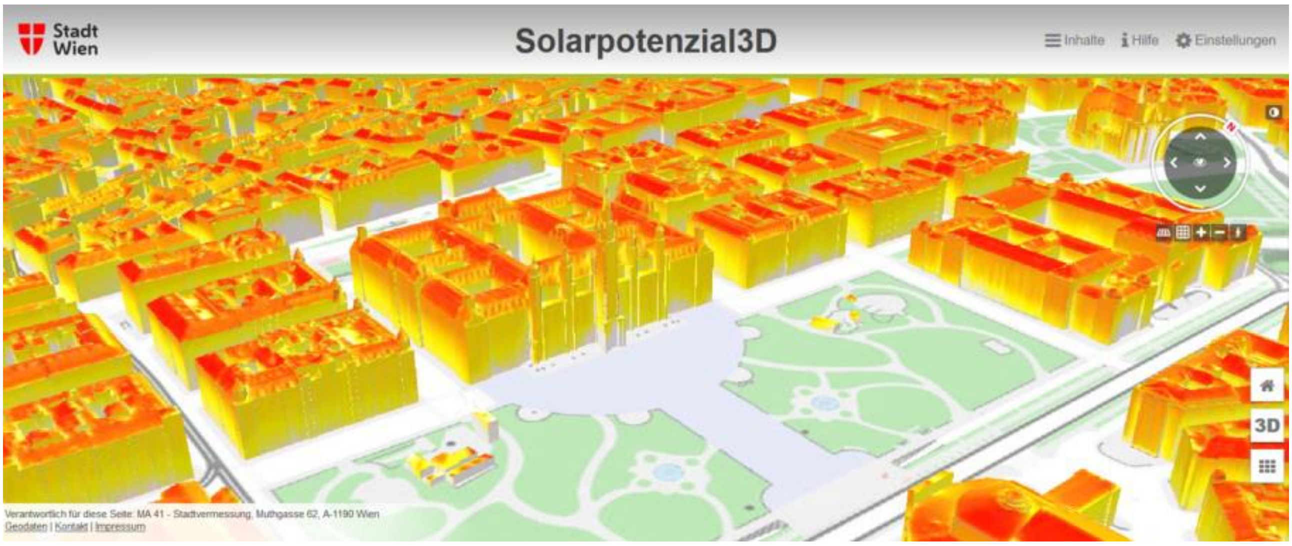


Fig. 3. Interactive urban planning – north/northwest railway station Vienna (© City of Vienna, Surveying and Mapping – Department 41)



Verantwortlich für diese Seite: MA 41 - Stadtvermessung, Muthgasse 62, A-1190 Wien
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Fig. 4. Simulation solarpotential Vienna (vcMap) (© City of Vienna, Surveying and Mapping – Department 41)

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[4] See footnote 2.

Due to the great interest in the effects of events in urban living spaces, in both small scale and citywide analyses, simulations form the third use case. Based on the Digital geoTwin various simulations, e.g. solar potential (see Fig. 4), flood scenarios, disruptive events etc. can be carried out. Thereby effects of planning can be calculated in advance and considered in decision-making processes. By using relationships between linked databases and simulation results, analyses and calculations can be executed on each 3D-object of the city.

Summary

Within the project "Digital geoTwin" a semantic, virtual 3D replica of Vienna is developed. The main goal is to automatically derive temporal and contentual coherent geodata products from the Digital geoTwin. Furthermore, use cases have been defined to incorporate the Digital geoTwin into a future Digital Twin of the City of Vienna.

References

Lehner, H. and Dorffner, L. (2020). 'Digital geoTwin Vienna: Towards a Digital Twin City as Geodata Hub', *PFG – Journal of Photogrammetry, Remote Sensing and Geoinformation Science 88*, pp. 63–75. doi:10.1007/s41064-020-00101-4.

City of Vienna's activity in large scale Mobile Mapping and related image based Artificial Intelligence

Digitizing the public space – Project "Wien gibt Raum"

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Keywords: *Spatial Inventory—Surveying—Computer Vision—Kappazunder—Big Data*

CHNT Reference: Eysn, L. (2021). 'City of Vienna's activity in large scale Mobile Mapping and related image based Artificial Intelligence. Digitizing the public space – Project "Wien gibt Raum"', in Börner, W., Rohland, H., Kral-Börner, C. and Karner, L. (eds.) *Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020.* Heidelberg: Propylaeum.
doi:10.11588/propylaeum.1045.c14487

In 2017 the City of Vienna – Department of Surveying and Mapping (MA41) initially performed a large terrestrial mobile mapping campaign. The public space was digitized using a purely image-based car mounted mobile mapping system, collecting image data every three meters along track. Beside the data acquisition, where over 30 million images were collected and georeferenced with a spatial accuracy better than 10 cm, 3D Information was derived from the images using a dense image matching approach. Using an artificial intelligence approach, all images were anonymized by blurring areas showing people and license plates.

The processed data (100 Terabytes) are published in a web-based viewing system, the so-called "Kappazunder", which is used by City of Vienna's staff to gain digital information with respect to administrative tasks within the public space. Examples for such tasks are simple distance measurements, or a visual inspection of the local situation. Based on this system, geodata was created and updated by semi-automatically extracting object information from the imagery, as for example the location of traffic signs (over 100.000 positions) or other aspects of selected city furniture. This task was carried out by using human intelligence. Information regarding the project "Wien gibt Raum" and the mobile mapping campaign can be found in Strondl et al., 2018, whereas information regarding the examination of city furniture can be found in Falkner and Eysn, 2019.

In summer 2020, a new car based mobile mapping campaign was launched, using enhanced sensors to capture approximately 4600 km of the public space. A panoramic camera system with 250 Megapixels captures imagery, whereas a Lidar system captures dense 3D information. The acquired data is georeferenced and anonymized to a very high-quality standard. Using these data, the web-based viewing system Kappazunder is filled with fresh data. Two epochs of data (2017 and 2020) will be made available to City of Vienna's staff, to support tackling of their daily business.

Using the 2017 car based mobile mapping data, first tests in the field of image based artificial intelligence were performed. These activities were led by the information technology departments MA01 PACE and MD-OS PIKT. In a proof of concept, information regarding traffic signs is automatically determined from the data. The survey grade mobile mapping data enables the transformation of detected objects into 3D space, which is mandatory with respect to the idea of spatially inventorying the public space. Based on a subset of the mobile mapping data, neural networks are trained and applied. Two different neural networks cover the tasks of feature detection and feature classification.

The result are georeferenced and classified geodata, representing selected objects within the public space. Initial results show, that especially training the neural network can be time consuming, and the quality and quantity of the training set is highly correlated with the overall accuracy of the resulting objects after inference. However, the potential of this technology is high, and a completeness and correctness greater than 95 % can be achieved, if the system is well trained. Beside the statistical aspect, the processing framework (for example data handling, data standards, interfaces, data storage, processing power, quality check) is challenging and needs to be set up for future analyses.

In addition to the car-based data collection in 2020, an aircraft based mobile mapping system captures nadir images (116 Megapixels) and oblique images (80 Megapixels), covering the whole city with aerial imagery. These data will be input for multiple applications, as, for example, refreshing the annual orthophoto or performing image based dense matching.

Both, the car based and the aircraft based mobile mapping data, can be a sufficient input for automatic analyses in a modern artificial intelligence framework, which is currently developed. However, the future intention of this framework is an automatic acquisition of spatial object information to update different geo-databases, which may feed a digital twin of the City of Vienna with updated object information.

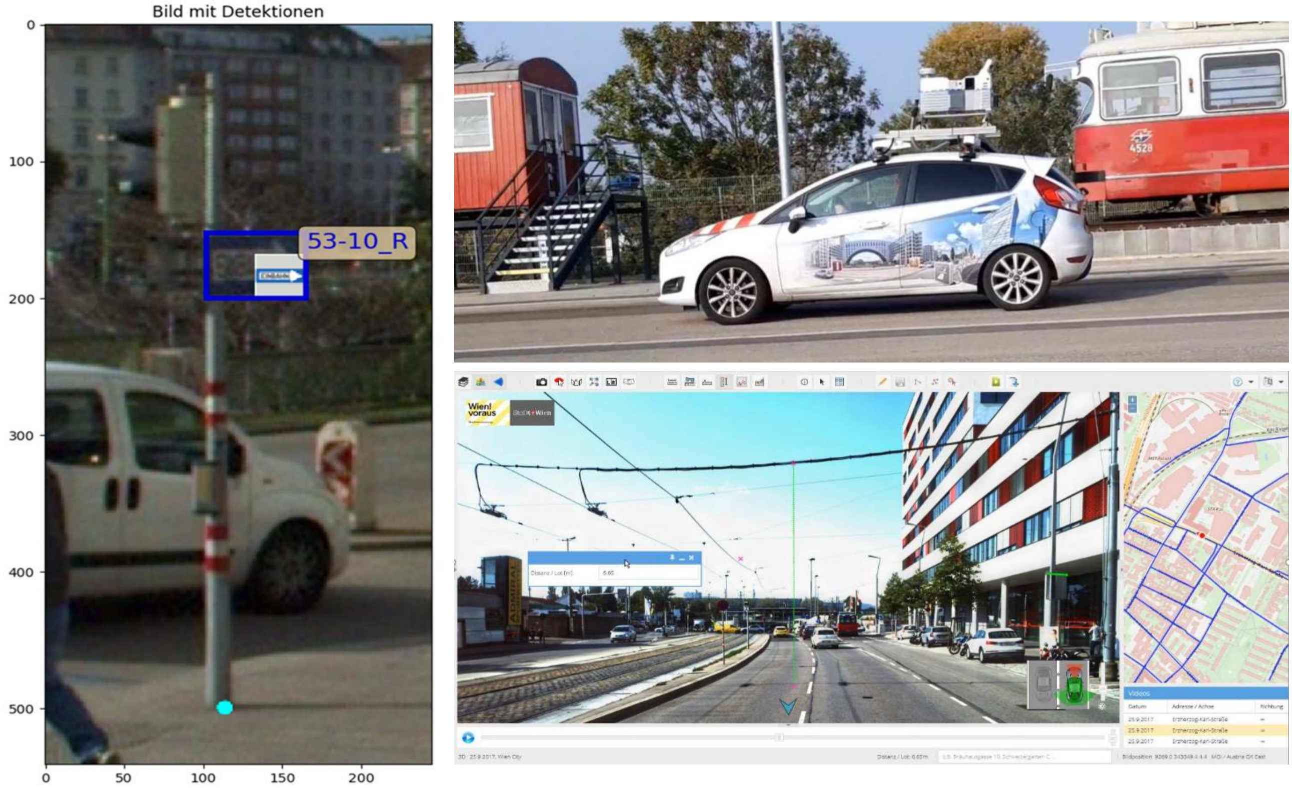

Fig. 1. Left: Automatically detected and correctly classified traffic sign; Top: Mobile Mapping Car 2020 equipped with GNSS, IMU, Lidar and a panoramic camera system; Bottom: Web based viewer system “Kappazunder”, showing a simple height measurement. © City of Vienna – Department of Surveying and Mapping (MA 41)

Inventorying and updating the various objects within the public space of Vienna is complex, since a numerous number of challenges need to be tackled. The possibilities of modern mobile mapping and the related high-resolution sensor technology opens up a wide field of applications, and are a fruitful input for statistical analyses, as, for example, the emerging technology of artificial intelligence. The City of Vienna and the Department of Surveying and Mapping (MA41) are heading towards this new technology, by acquiring high quality geodata and supporting the setup of an artificial intelligence pipeline.

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(Open) Data in the City of Vienna

Urban Data Platform smartdata.wien

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Gerhard HARTMANN, City of Vienna, Austria

Keywords: *OGD—Urban Data Platform—IoT—Sensors—Government—Open Data*

CHNT Reference: Pfaffenbichler, F. X. and Hartmann, G. (2022). '(Open) Data in the City of Vienna. Urban Data Platform smartdata.wien', in Börner, W., Rohland, H., Kral-Börner, C. and Karner, L. (eds.) *Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020*. Heidelberg: Propylaeum.
doi:10.11588/propylaeum.1045.c14488

Open Government Data

A city has a huge amount of data that it urgently needs for various tasks. This data is not only used for internal processes but is also offered to the public in various ways. Vienna was actually the first city in the German-speaking world to publish open government data already in 2011. Data represents the stable and long-living core of information management in the City of Vienna, the digital IQ of the City is increased by the data. They form the foundation for information and knowledge and are an essential production factor for a "smart, intelligent and digital" City. The precondition for this is the defined Data Excellence Strategy—a data strategy that includes all necessary measures for the timely provision of reliable data in the required quality, with the vision that the City of Vienna will become a "Data excellent" Data Capital City.

Open data bring transparency and participation to society by being used for projects or by data journalists. They enable fact-based participation and objective discussion. The city's open data and open interfaces have led to remarkable innovation, as more than 280 new apps have been developed by third-party software engineers using Vienna's Open Data. The scientific community uses Open Data as a database for research projects. For students, open data are more exciting than any sample data sets. For the economy, Open Data is the fuel for innovation and the basis for new business fields and diverse applications, such as apps, websites, analyses or other services. The administration itself also benefits from open data, for example because it can easily use data from other agencies or as a basis for digitisation projects. The data is thus part of the departments' knowledge management.

As this is a very important point for public administrations, we synchronize our open data with the European Data Portal and are part of the cooperation "OGD D-A-CH-LI", which is an Open Government Data movement in the German-speaking world.

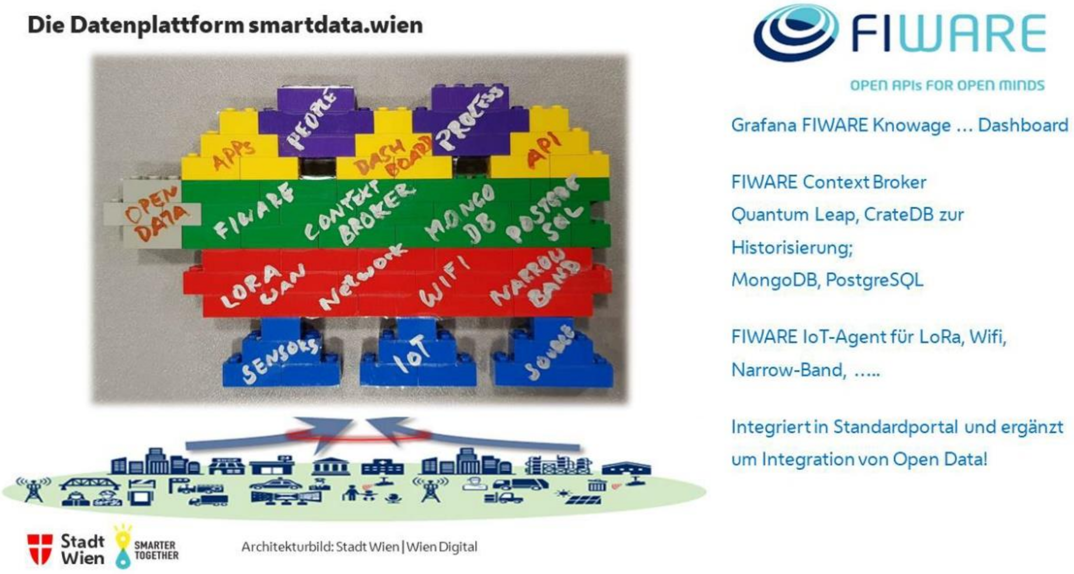
Urban Data Platform

The guiding principle "Open by Default" is essential for access to public data of the City of Vienna: The city administration opens up publicly classified data, documents and services in a machine-readable form and free of charge since 2011 on https://data.wien.gv.at. For integration of multiple datastreams from IoT devices and Open Data on the same datalake we use the FIWARE based platform solution https://smartdata.wien.gv.at.

The urban data platform Vienna (https://smartdata.wien.gv.at) takes open data to a whole new level. Its data aggregation and analysis capabilities are based on the European Commission's Context Broker building block, which can sort through data of all sorts and sources from all across the city.

Smartdata.wien was developed as part of the joint EU project "Smarter Together" of the cities of Lyon, Munich and Vienna on the topic of Smart City, and will continue to be used for various smart city projects in areas such as energy, buildings and mobility.

The technical core of the urban data platform is the FIWARE Context Broker, which allows the platform to offer real-time information through visual dashboards that cater to the needs of all stakeholders from residents to city officials and software developers. The platform can facilitate day-to-day activities, such as urban mobility, environmental monitoring, urban infrastructure, energy efficiency and more.



Die Datenplattform smartdata.wien

Grafana FIWARE Knowage … Dashboard

FIWARE Context Broker
Quantum Leap, CrateDB zur Historisierung;
MongoDB, PostgreSQL

FIWARE IoT-Agent für LoRa, Wifi, Narrow-Band, …..

Integriert in Standardportal und ergänzt um Integration von Open Data!

Architekturbild: Stadt Wien | Wien Digital

Fig. 1. architecture picture data platform Vienna smartdata.wien. (© City of Vienna).

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European Commission, City of Vienna (2020). 'The number one smart city in the world uses CEF Context Broker to effectively manage Big Data, Success Story CEF Digital Building Blocks', Brussels/Vienna, Available at https://ec.europa.eu/cefdigital/wiki/display/CEFDIGITAL/2020/02/06/The+number+one+smart+city+in+the+world%2C%20+Vienna%2C+uses+CEF+Context+Broker+to+effectively+manage+Big+Data (Accessed: 13 January 2019).

WienBot

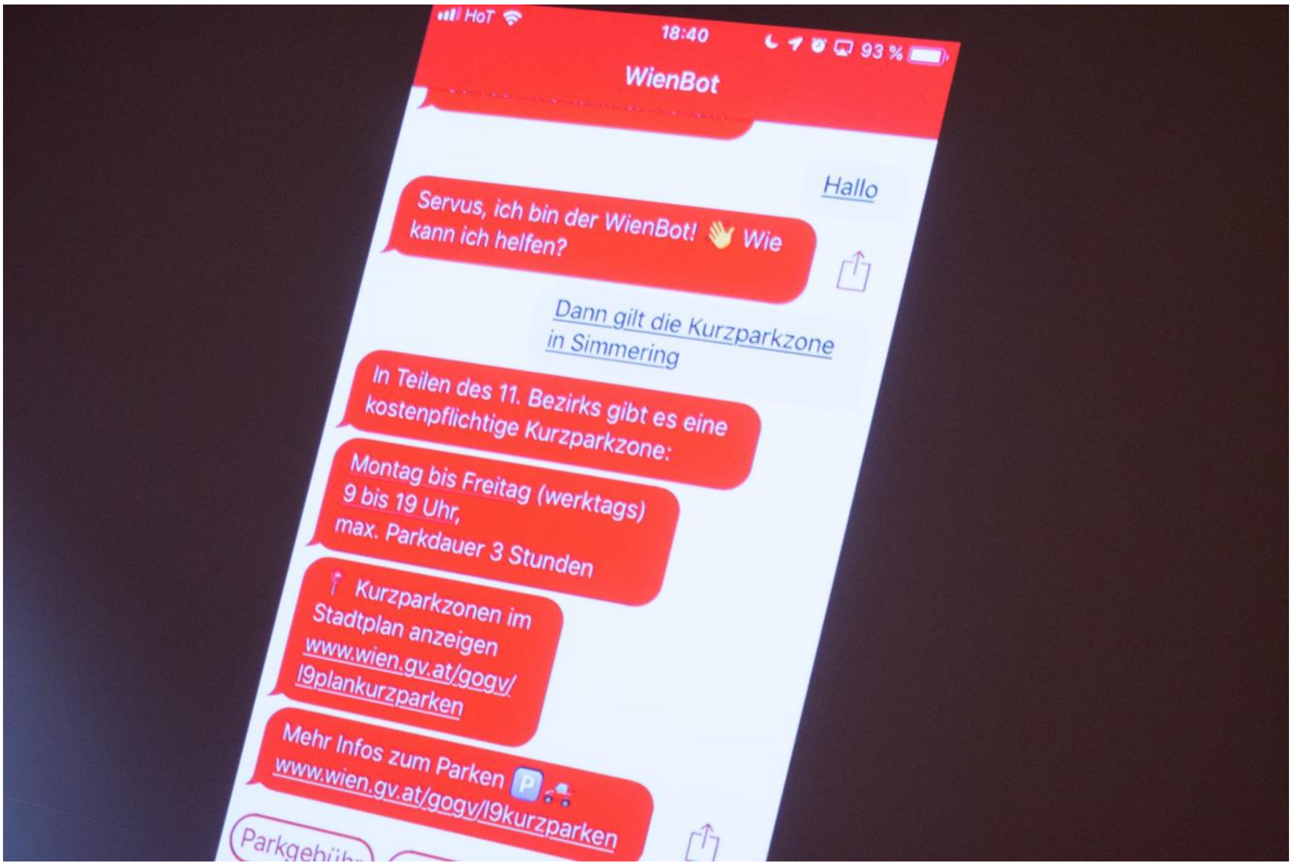
AI counters Covid-19 disinformation

Sindre WIMBERGER, City of Vienna

Keywords: *Voice Assistant—Chatbot—Artificial Intelligence*

CHNT Reference: Wimberger, S. (2022). ‘WienBot. AI counters Covid-19 disinformation’, in Börner, W., Rohland, H., Kral-Börner, C. and Karner, L. (eds.) *Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020*. Heidelberg: Propylaeum.
doi:10.11588/propylaeum.1045.c14573

During the COVID 19 pandemic the WienBot became an even more important information channel for crisis communication. By using artificial intelligence and interfaces to public, central data sources, continuously updated and verified information could be guaranteed.



Hallo

Servus, ich bin der WienBot! 👋 Wie kann ich helfen?

Dann gilt die Kurzparkzone in Simmering

In Teilen des 11. Bezirks gibt es eine kostenpflichtige Kurzparkzone:

Montag bis Freitag (werktags)
9 bis 19 Uhr,
max. Parkdauer 3 Stunden

📍 Kurzparkzonen im Stadtplan anzeigen www.wien.gv.at/gogv/l9plankurzparken

Mehr Infos zum Parken 🅿️🚗 www.wien.gv.at/gogv/l9kurzparken

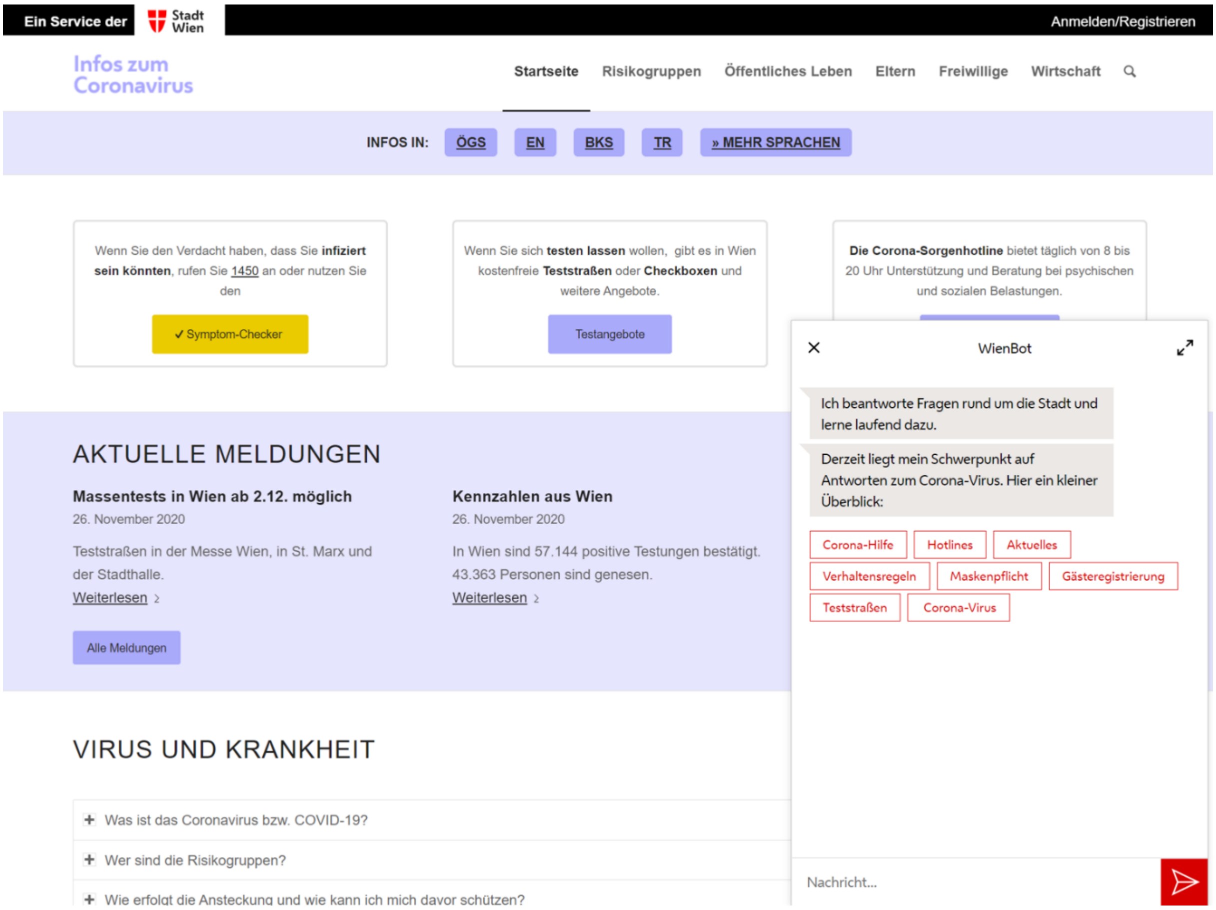
Fig. 1. The WienBot answers natural language questions of the users, providing them with relevant information. © Presseinformationsdienst der Stadt Wien (PID)/Votava Martin.

A ChatBot for crisis communication

Particularly in times of crisis, there is an increased need for information among the population. Public services experienced a particular stress test with the beginning of the Covid-19 pandemic. They faced the challenge of coordinating and communicating daily Covid-19 updates on protective measures and instructions to the citizens.

In order to relieve the burden on call centres and health advice services and to provide citizens with targeted and quick answers to their questions, the City of Vienna used its digital assistant “WienBot” to set up a “CoronaBot” at the beginning of the corona crisis. Within a few days, citizens were able to access relevant information about Covid-19 via the digital assistant. In the following weeks, WienBot was continuously expanded with current information, trained and improved by the questions asked. The plan was to guide citizens through times of crisis on a channel they already trusted, and to ease the burden on call centres. This plan worked out perfectly: The City of Vienna’s digital assistant has answered more than two million questions on Covid-19 since the beginning of the corona crisis.

In 2017, Vienna was the first city in the world that launched its own intelligent voice assistant. With its development, the City of Vienna did not only respond to a digital trend. By harnessing technical innovation and placing citizens’ needs at the centre of communication, WienBot supports Vienna’s Smart City strategy, which literally calls for “high quality of life for everyone in Vienna through social and technical innovation in all areas, while maximising conservation of resources.”



Wenn Sie den Verdacht haben, dass Sie **infiziert sein könnten**, rufen Sie 1450 an oder nutzen Sie den

Wenn Sie sich **testen lassen** wollen, gibt es in Wien kostenfreie **Teststraßen** oder **Checkboxen** und weitere Angebote.

Die Corona-Sorgenhotline bietet täglich von 8 bis 20 Uhr Unterstützung und Beratung bei psychischen und sozialen Belastungen.

AKTUELLE MELDUNGEN

Massentests in Wien ab 2.12. möglich
26. November 2020
Teststraßen in der Messe Wien, in St. Marx und der Stadthalle.

Kennzahlen aus Wien
26. November 2020
In Wien sind 57.144 positive Testungen bestätigt. 43.363 Personen sind genesen.

VIRUS UND KRANKHEIT

+ Was ist das Coronavirus bzw. COVID-19?
+ Wer sind die Risikogruppen?
+ Wie erfolgt die Ansteckung und wie kann ich mich davor schützen?

Ich beantworte Fragen rund um die Stadt und lerne laufend dazu.

Derzeit liegt mein Schwerpunkt auf Antworten zum Corona-Virus. Hier ein kleiner Überblick:

Fig. 2. The information homepage of the City of Vienna concerning the coronavirus-pandemic also included the WienBot to allow interactive questions by the users. © PID.

Since the launch of WienBot, citizens have enjoyed using the channel and are constantly involved in its further development e.g. by asking questions on relevant topics. As a result, the digital assistant is in a constant process of learning and expanding its knowledge. Furthermore, citizens are already familiar with the channel as a trustworthy source of information, which is extremely beneficial during a crisis. As a mass communication channel during the crisis, WienBot fully played its strengths by using artificial intelligence and the integration of trusted public data sources.

WienBot becomes “CoronaBot”

Especially at the beginning of the pandemic uncertainty, fear and lack of clarity were widespread among citizens. Most of them had never experienced a crisis like this before. Therefore, it was crucial for the City Administration to provide orientation and to be a reliable source of information to large parts of the population.

This is exactly where the digital assistant WienBot came in as an essential resource. During the Covid-19 lockdowns in particular, the digital assistant allowed the City of Vienna to directly reach out to the population via their trusted channel, answering their most urgent questions, helping prevent misinformation, and guiding citizens trough times of crisis.

For this purpose, WienBot was trained with several thousand questions and technical terms on the topic of corona. The biggest effort was to prepare the complex topic in a short and simple way. In addition, all effects of the lockdown had to be incorporated into already existing answers within a very short time. Current information (e.g. from expert sources like AGES, the Austrian Health and Food Safety Agency) was continuously updated via interfaces to public databases, and the answers were automatically prioritised according to relevance and urgency.

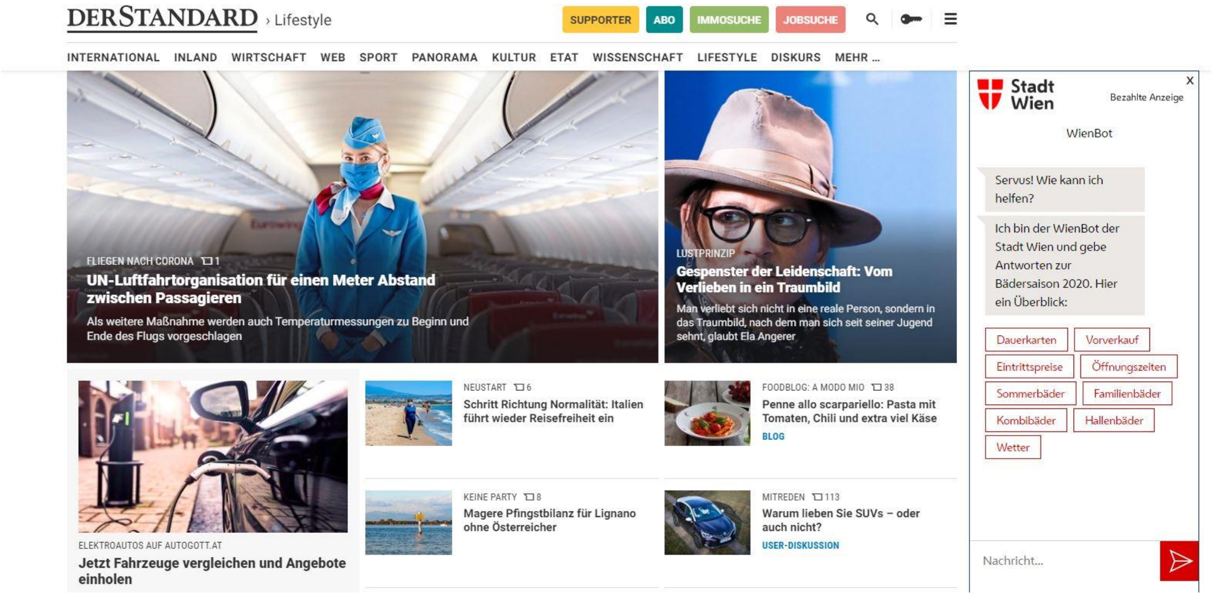
At the same time, the questions asked by users were an excellent basis for identifying topics on which the local population needed more information. Providing continuously updated information, the bot also relieved the burden on the municipal health services.

Turning WienBot into a CoronaBot so quickly was only possible due to the close and good cooperation of various departments of the Vienna City Administration. Two municipal departments, the Press and Information Services (MA53) and the Information Technology Department (MA01), provided the editorial and technical basis for integrating Covid-19 information into WienBot. Intensive cooperation with the Public Health Office and its medical officers ensured that only checked and reliable medical information was offered to the population. During the entire process, everyone involved in the CoronaBot project kept in mind accessibility requirements and provided information in simple language.

Answering frequently asked questions faster than Google

The strengths of automated communication could thus be fully exploited: WienBot became known for answering questions on restricted opening hours, current guidelines, protective measures or Corona aid measures “faster than Google” because the bot provides short, precise answers rather than a list of links. With each new question, WienBot learned independently, saving time in the search for the right answer and at the same time relieving the limited resources of public health services and hotlines.

As a part of a comprehensive campaign by the City of Vienna, WienBot was placed as an interactive banner in leading Austrian online media like *orf.at* (the news website of the Austrian public service broadcaster ORF) and *derstandard.at* (daily newspaper) (Fig. 3). The fully functional widget answered questions on corona or the current situation in Vienna's public swimming pools. The latter topic was not a random choice because the relevant provisions in the Covid-19 regulations advised the population to inform themselves online about free capacities before setting out to a public pool.



FLIEGEN NACH CORONA 1
UN-Luftfahrtorganisation für einen Meter Abstand zwischen Passagieren
Als weitere Maßnahme werden auch Temperaturmessungen zu Beginn und Ende des Flugs vorgeschlagen

LUSTPRINZIP
Gespenster der Leidenschaft: Vom Verlieben in ein Traumbild
Man verliebt sich nicht in eine reale Person, sondern in das Traumbild, nach dem man sich seit seiner Jugend sehnt, glaubt Ela Angerer

ELEKTROAUTOS AUF AUTOGOTT.AT
Jetzt Fahrzeuge vergleichen und Angebote einholen

NEUSTART 6
Schritt Richtung Normalität: Italien führt wieder Reisefreiheit ein

FOODBLOG: A MODO MIO 38
Penne allo scarpariello: Pasta mit Tomaten, Chili und extra viel Käse
BLOG

KEINE PARTY 8
Magere Pfingstbilanz für Lignano ohne Österreicher

MITREDEN 113
Warum lieben Sie SUVs – oder auch nicht?
USER-DISKUSSION

Servus! Wie kann ich helfen?

Ich bin der WienBot der Stadt Wien und gebe Antworten zur Bädersaison 2020. Hier ein Überblick:

Fig. 3. To increase outreach, WienBot was placed as an interactive banner in leading Austrian online media outlets. © PID.

Impact

Since its launch, WienBot has focused on the needs of local citizens, who are actively involved in the ongoing AI learning process via the questions they ask. Artificial intelligence analyses these new questions, and editorial review processes guarantee that WienBot constantly learns and expands its knowledge. Because of its valuable user feedback, WienBot is now a central communication channel of the City of Vienna. It is integrated in:

- the City of Vienna app (Search)
- wien.gv.at-search (direct response above the search results)
- coronavirus.wien.gv.at (web widget)
- impfservice.wien (web widget)
- allesgurgelt.at (web widget)
- gesundheitsverbund.at (web widget)
- Knowledge management of Vienna's Community Service (interface)

This is also reflected in the rapidly increasing number of questions, as seen in Figure 4. Since the start of the Corona pandemic, WienBot has already provided 2,000,000 answers on this specific topic. This has significantly supported citizens and relieved the burden on hotlines. Currently, people submit about 500,000 questions to WienBot every month. An average 60% of all answers are related to the coronavirus or Covid-19.

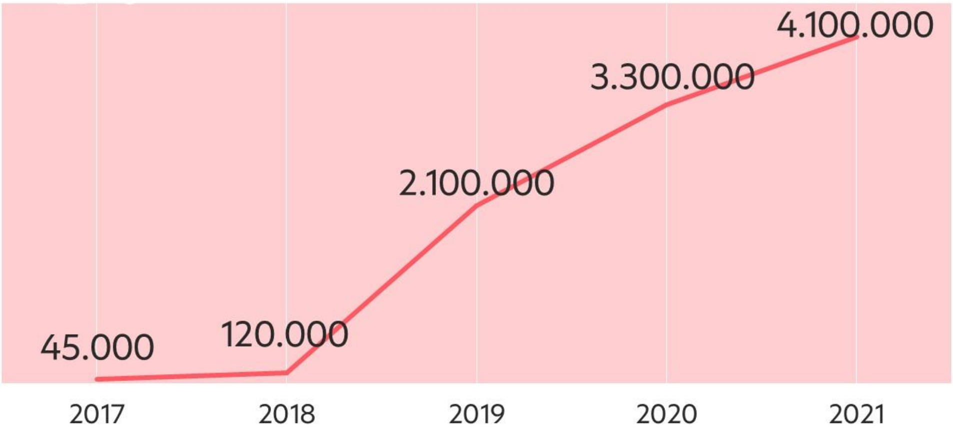


Fig. 4. The increasing number of questions issued to the WienBot by the users reflect the growing importance of the WienBot as a communication channel of the City of Vienna. © PID.

Cooperation

The team behind WienBot has showcased its talent several times to delegates from other Austrian cities. It has provided an exceptional case study demonstrating how valuable a digital assistant can be for a public institution. This quickly led to the development of a network in Austria. Cities like Graz and Linz as well as the Austrian Association of Cities are in constant exchange with the WienBot team. The team's experience is also very much appreciated across national borders: the WienBot creators have been invited to give lectures in Germany and have maintained an active exchange with the cities of Berlin and Munich as well as the German Ministry of the Interior. The ongoing exchange also helps to continuously improve the service and incorporate new and fresh ideas.

Lessons learned

The most important lessons that the team has learned about the digital assistant are

User first-approach:

With their questions, the users train WienBot and are thus continuously involved in the process, letting the City of Vienna know which answers are needed most urgently and which topics need to be expanded.

Content first-approach:

Questions and answers by WienBot are prepared specifically for the digital assistant; they need to be short and easily understandable for the citizens. Therefore, simply copying and pasting existing text does not suffice to meet the specific needs of WienBot users.

Voice first-approach:

The accessibility of WienBot is one of its core characteristics, especially thanks to its great natural language support. Besides chatting with WienBot, users can ask WienBot questions – even in Viennese dialect. Voice input is important for persons with special needs, but users' interactions with technology are generally changing. A few years ago, written words were the most widely used input method, speech is currently on the fast lane. Based on its own experience, the WienBot team recommends not to think too much in formulated and written sentences but way more in spoken language.

Special Session:
CHNT 25 – The success story continues

Wolfgang BÖRNER | Irmela HERZOG

Call

Wolfgang BÖRNER, Museen der Stadt Wien – Stadtarchaeologie, Austria
Irmela HERZOG, The Rhineland Commission for Archaeological Monuments and Sites, Bonn, Germany

Keywords: *CHNT, New Technologies, Computer, Archaeology, Cultural Heritage,*

At the 25th CHNT conference this session offers the opportunity not only to look back on 25 years of computational archaeology and new technologies in cultural heritage, but also to learn from the past. In the first years, the name of the conference was still "Archäologie & Computer", and in the proceedings of the first conference, Ortolf Harl, the head of the Vienna's Urban Archaeology department at that time, wrote: "To master the plenitude of the archaeological material it is inevitable to use a computer. Well, a computer is a must! … However: with the meal the appetite grows. Well: a conference is a must!"

These statements are still valid, although computers have changed a lot, and are nowadays often integrated in smart phones or tablets. The latter can be used to control drone flights with digital cameras taking pictures of cultural heritage sites. Modern technology allows creating a 3D model based on these pictures, and this is only one of many innovative approaches that appeared during the past 25 years.

This session invites researchers to present their new results that were inspired by a poster or a talk given at a CHNT conference, by reading a publication of such a talk or poster, by a discussion with colleagues at a round table, during the breaks or the social events at the conference or by attending one of the CHNT workshops. Papers on CHNT projects involving colleagues from different disciplines that first met at a CHNT conference may also be submitted to this session. It is also possible to give an update on projects that were first presented at a CHNT conference some years ago and are still evolving (e.g. web sites) in a short contribution to this session. Moreover, talks that review the development of a specific CHNT topic during the past decade or a longer period of time are welcome.

With gratitude: An affectionate, personal review of (almost) 20 years unbroken CHNT participation

David BIBBY, Germany

> **Authors note:** This is not a scientific paper. It is a reminiscence of two decades of CHNT – a personal collection of impressions, recollections, people and project spin offs from the CHNT. The text is largely a one-to-one transcription of the talk given at CHNT 25 in Vienna 2020. The style is accordingly conversational, illustrated by "snapshots".

CHNT Reference: Bibby, D. (2022). 'With gratitude: An affectionate, personal review of (almost) 20 years unbroken CHNT participation', in Börner, W., Rohland, H., Kral-Börner, C. and Karner, L. (eds.) *Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020*. Heidelberg: Propylaeum.
doi:10.11588/propylaeum.1045.c14490

In 2001, my love affair with Vienna and the CHNT began. It didn't start in Vienna. It started much earlier in Bermuda at the then Bermuda Maritime Museum on the recommendation of its Director Dr. Edward Harris, the inventor of the Harris Matrix. After creating the Harris Matrix Edward Harris turned his attention to transforming Bermuda's Maritime Museum into Bermuda's National Museum include all dockyard fortifications and now covering an area of for total of 16 acres.

National Museum of Bermuda (nmb.bm)

When Edward Harris introduced his Matrix in the UK in the mid-1970s he initially caused quite a stir and even outright opposition from some archaeologists unable to understand its meaning and the revolutionary advance in stratigraphic theory it postulated. This we tend to forget. One of the few scientists who actually understood the significance and scope of the Harris Matrix and stood by and supported Edward Harris throughout those early years was Frances Lynch-Llewellyn at the then

Colleg yr Bryfisgoll Gollgeth Cymru – The University College of North Wales in Bangor. Later, Frances would become my archaeology Professor, for which I am eternally grateful, but that's another story…

When I met Edward Harris in the mid-1980s there was no need to break any ice at all. When he heard I had been student of Frances Lynch his attitude – in his typical, buccaneering manner was. "Any friend of Frances' is friend of mine…" My personal and scientific relationship with Edward Harris has been very rewarding over decades and I was lucky enough to be invited to contribute both to the second edition of "Principles of Archaeological Stratigraphy" as well as to the companion volume "Practices of Archaeological Stratigraphy".

Stratigraphic theory was the overarching theme of the 2001 Workshop "Archäologie und Computer" in Vienna, as the CHNT was then called. Wolfgang Börner, then and still heart and soul of the CHNT, invited Edward Harris. Edward Harris, in turn, suggested to Wolfgang Börner, that he should invite me. For this invitation I am eternally grateful to both Wolfgang Börner and Edward Harris. It was that invitation that literally "changed my life". A statement not meant as possible "tear jerker". It is simply a statement of fact. That invitation sowed the seed for a "proper" scientific career in European archaeology rather than possibly remaining just another British journeyman on the German excavation circuit.

In 2001 I talked about software integration of the Harris Matrix into archaeological data bases and CAD – reporting on work which was then part of a very successful cooperation with the Martin Schaich's Arctron Company (Start – ArcTron) I take this late opportunity to sincerely thank Martin and his team.

In 2001 Harris was already discussing the connection between stratigraphy and GIS. It was the first time I'd heard about GIS in connection with Archaeology. Then it was still very new, at least to me. But, that's the fascination of the Vienna event, is it not? The CHNT is always been up to speed. Even ahead of its time, having a nose for innovation, an inkling for the next important up and coming thing. All its participants profit from that "drive". It was at the Vienna Workshop that I first saw a Laser Scanner – also in 2001. Archaeological-technical pioneer Martin Schaich had one of the first ones – a RIEGL Z 210. In the following years the same went for SFM, UAVs and the general concept of 3D and virtual and augmented reality in archaeology.

Another fundamental, important and recurring theme of the CHNT is the spin offs it creates. Like the trunk of a tree, every year the CHNT grows from strength to strength, always developing new branches, creating opportunities for other projects which probably would not have happened without the catalyst that is the CHNT Vienna.

I re-met Irmela Herzog in Vienna in 2001, German Archaeology Prize winner and well known to anyone into stratigraphy and archaeological computing.

She introduced her new program Stratify to replace her original program Harris.

It was also in my first year, 2001, that I met Benjamin Ducke. Then still a student. Now head of archaeological computing at the German Archaeological Institute in Berlin and an internationally respected expert in the field of archaeological information technology. That fortuitous meeting let to fruitful ongoing co-operations between Baden-Württemberg and Berlin, lasting over two decades and ultimately resulting in the development of the (now standard) Survey2GIS software for easily transferring survey data to fully attributed GIS-projects. Survey2GIS was neither born in Vienna or conceived there. But Vienna is where the original matchmaking was done. The “baby”, Survey2GIS, is open source and freely available to anyone who wants to use it: About | Survey2Gis (survey-tools.org). Survey2GIS has one more Vienna connection, even inspiration – a lecture held in Vienna by Karen Lund and Hakan Thoren from the Swedish National Heritage Board on their excellent (but expensive) ESRI-based Intrasis GIS-System. That inspired me to try something similar, but on an open source basis and in cooperation with Benjamin Ducke, without whose programming expertise the development would not have been possible.

Back to the first day of my first conference, the tale of which still remains unfinished. In the evening there was some fine entertainment in the “Centimeter” Pub

in the Josefstadt near the Rathaus. Edward Harris, yes, that Edward Harris

and Dominic Powslesand, yes that Dominic Powsland (with Keith May to his right),

dancing on the tables at a late hour celebrating their reunion three decades after they had been digging companions in Winchester… Dominic Powslesand was in Vienna under the chaparoneship of Keith May (Keith really did try his best!) to present stratigraphic aspects of his long-term project in Hesleton Parish project in Yorkshire. There are unfortunately no surviving Photos of the dancing – or at least I haven’t been able to find any. Or nobody is willing to let me use them. Edward Harris even denies that it happened. But believe me, it did. It happened! This Photo is from the beginning of the evening. Things were heating up already!

Ever since I had been a student, Domenic Powslesand, innovator and infant terrible of British Archaeology and one of the first computer archaeologists in the UK had been an idol for me. How appropriate I should meet him for the first time in Vienna – and, thankfully, he was still an infant terrible! Fast forward to (much) later: to sitting together with Dominik and Keith. Hungry, 3:30 in the morning of the following day in the legendary Café Drexler on Wiener Zeile next to the Naschmarkt.

We all thought we were going to stay hungry. When asked by Herr Drexler what he could offer us for breakfast, Herr Drexler replied “ha mi nix”. Blessed or blighted with speaking both German and English I interpreted that as his special Viennese German way of saying “wir haben nichts”, meaning “we have nothing” or “we can offer you nothing” – “Ha mir nix”. In reality in his special Viennese English he was offering us ham and eggs! What a wonderful introduction to Vienna and its culinary delights! Satisfiedly full of eggs and rashers the day ended in the twighlight of the next morning and if the truth were to be known a little later than originally planned the day before in the Wappensaal at the conference!

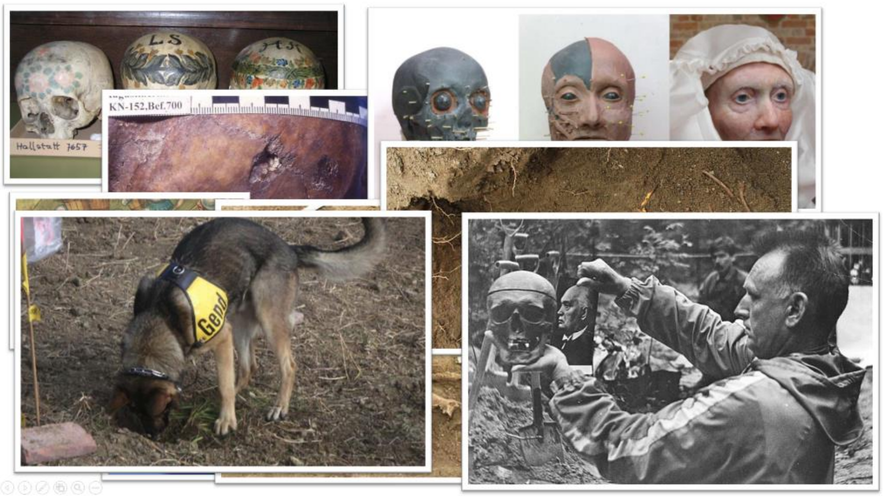
Medium-fast forward. This time to 2005 when Ann Deagrave from Brussels, answering an invitation to join the session I was chairing, first took part in the (then still) “Workshop”. Ann has since become a mainstay of the Vienna meeting and an established CHNT committee member. As city archaeologist of Brussels she gave a first talk entitled “Inventorying the archaeological record: the example of the Brussels Capital Reigion, Belgium". In a second talk she described "14 years of archaeological recording in the Brussels Capital Region, Belgium: past, present and future".

Ann Degraeve, Vienna, Wappensaal, 2005

Ann Degraeve, Brighton Beach, UK, 2016

Meeting Ann was another life-changing event for me – once again made possible by Vienna – resulting in not just a fruitful scientific cooperation in Vienna and beyond but also a life-long friendship. In Vienna we jointly chaired a number of sessions – most notably perhaps the long running "mini-series" or "mini conference within the conference", "The Dead" (apologies to James Joyce) which we invented 2012 perfectly in tune with both the CHNT and Vienna's immortal bond to morbidity…

In later years, “The Dead” received reinforcement from Karin Wiltche-Schrote from the Vienna Natural History Museum and human anthropologist Raphael Panhusen from the Free University in Amsterdam. It ran for 4 years from 2012 to 2016 and we had some memorable contributions:

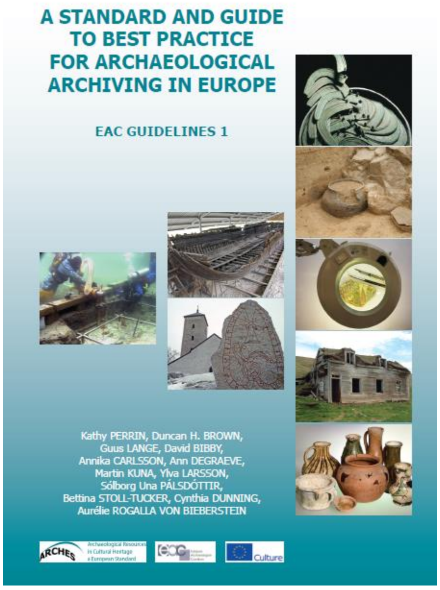


- Skulls from Hallstatt in the national History Museum by Karen Schrote Wiltche
- Traumatic violent death of a fighting knight from Konstanz in the Appenzel wars by Joachiom Wahl, Hildegard Bibby and David Bibby
- Facial Reconstructions by Maja D’Hollsby from the university of Amsterdam
- Bizarre Circus Horse and Snake burials in Turku, Frinland by Lisa Steppänen from the university there
- The Austrian Cadaver Dog Core sniffing out second world war corpses by Thomas Potoschnig, Austrian Association of Forensic Archaeology
- And the moving story of the search for …. The first Estonian president Konstantin Päts by Peep Pillak of the Estonian Heritage Society

… to mention just a few. All accessible and very readable and in the proceedings of the CHNT.

I’ve already compared the CHNT to the trunk of a tree, with branches, creating opportunities for more project. And so it was with Ann Degraeve and myself. Vienna had a direct influence the EAC – the Europae Aechaäologie Consilium (European Archaeological Council) of which I was already a member when Ann and I first met. Ann came on board and we shared the chairmanship of the EAC working party on archaeological archives. The ultimate result being the EU-co-financed ARCHES

Project and the production of EAC Guidelines 1 The “Standard and Guide to Best Practice for Archaeological Archiving in Europe”, downloadable in nine languages:



A STANDARD AND GUIDE
TO BEST PRACTICE
FOR ARCHAEOLOGICAL
ARCHIVING IN EUROPE

EAC GUIDELINES 1

Kathy PERRIN, Duncan H. BROWN,
Guus LANGE, David BIBBY,
Annika CARLSSON, Ann DEGRAEVE,
Martin KUNA, Ylva LARSSON,
Sólborg Una PÁLSDÓTTIR,
Bettina STOLL-TUCKER, Cynthia DUNNING,
Aurélie ROGALLA VON BIEBERSTEIN

ARCHES Archaeological Resources in Cultural Heritage a European Standard

Culture

EAC Guidelines | European Archaeological Council (EAC) (europae-archaeologiae-consilium.org)

In fact, the road to ARCHES and the resulting EAC Guidelines has its origins in Vienna. It is a little-known fact that the final decision of the EAC-Archaeological Archives Working Group to actually go ahead and apply for the EU-grant which made ARCHES possible was made at a Working Group meeting during the 2009 CHNT, in a meeting-room kindly made available by Vienna City Archaeology in their offices in the Obere Augartenstraße.

Now back to 2004, another important year for new acquaintances. 2004 was Reiner Goldner’s first year in Vienna.

Reiner Göldner CHNT 18, 2013

Another lucky professional acquaintance for me and personal friend made in Vienna, leading to working productively together in Germany in the grand-sounding “Commission Archaeology and Information System of the Association of German State Archaeologists” – of which Reiner holds the chair. In 2004, standing next to me, our very dear departed friend Willem Beex spotted Reiner new and alone (as we all were once) after the last afternoon talk. Willem suggested we introduce ourselves and ultimately, the three of us spent a fine evening together. Anybody who knew Willem Beex will not be surprised at this kindness and friendliness. Please allow me to shed tear for him. I know you who knew who knew him will join me.

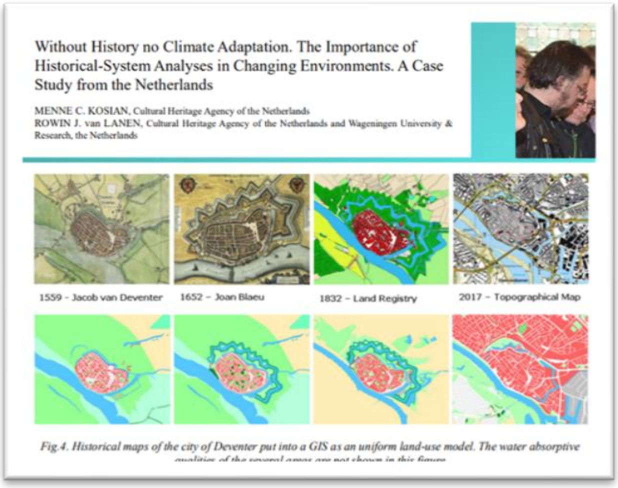
Willem Beex, 1962 – 2019

But that is also what the CHNT is about. Friendships made and friendships kept. Even if you don’t see each other from one year to the next you just come back to Vienna in November and as you climb the Rathaus stairs and approach the reception desk…

… and book table (some things never change!) you just know you've "come home" and will be able to take up the conversation just as you had left it and the previous twelve months simply dissolve in the dust of time. That is what it used to be like in pre-covid epoch. Hopefully it will still be the same, when it is possible to gather again easily and in person without "virtuals" and "hybrids".

Willem Beex was one of the first and one of the most active members of an ever-growing Dutch contingent with their base year for year at "Bendl" just to the North of the Rathaus on the Landesgerichtsstraße…

… an establishment upon which opinions differ. Whatever your opinion, the big Dutch contingent, with their beautifully prepared talks ranging from Menne Kosian (and friends') on urban GIS


Without History no Climate Adaptation. The Importance of Historical-System Analyses in Changing Environments. A Case Study from the Netherlands

MENNE C. KOSIAN, Cultural Heritage Agency of the Netherlands
ROWIN J. van LANEN, Cultural Heritage Agency of the Netherlands and Wageningen University & Research, the Netherlands

Fig.4. Historical maps of the city of Deventer put into a GIS as an uniform land-use model. The water absorptive

to Benno Ridderhofs unforgettable ride on the range with Colonel Custer…

give the CHNT as special gôut! And with the Dutch team you can always hard talk if you want to – though always good naturedly…

Every year Professore Giorgio VERDIANI car-convoys a lively group of Italians cis-alpino. I love them for their wonderful 3D architecture talks, humour, their never ending joyous mood, not to mention their singing!

Tempus fugit, and I've only just started scratching the surface! So allow me conclude by mentioning a few more of my personal CHNT and Vienna favourites….

It is impossible to pick out any more talks and lectures as better, or worse. There is no point in trying. Let’s just all agree we have all profited immensely from all of them and turn to other highlights – happy and interesting memories and a reminder of what we will hopefully experience again in better times to come…

The coffee breaks and all the wheeling dealing done and the fun had there!

The events at the Planungsamt:

The Lords Mayor’s reception:

With such highlights as the wonderful Viennese music of Cornelia Maier…

And where else in in the world do you get to hold seminars in somewhere like the Ahnensaal – the ancestral chamber in the Viennese Hofburg.

All these factors help to digest the new scientific knowledge and inspiration gained during the three days in November in Vienna. And that consistently over a quarter of a century!

For all these reasons and many more, the CHNT is important. It is where one first experiences the newest innovations in our discipline and Vienna's special positon in south-central Europe makes it perfect as a melting pot for scientists from the north, the south, the east and the west.

Now some thankyous. I thank Karin Aussere Fischer for her support and the participation of the City Archaeology in the CHNT up to and including 2020. I particularly thank Susanne Uhlirz for "German efficiency" and organisation talent and last but certainly not least and from the very bottom of my heart I thank Wolfgang Börner.

Wolfgang is "Mr. CHNT". Without him, the CHNT would, at the very least, be a quite different event. With the CHNT Wolfgang Börner has created a special atmosphere, a unique atmosphere. And in doing so he has always been able to count on top class special support of his family: So….

… a huge

THANK YOU TO THE WHOLE BÖRNER FAMILY!

And thank you to everybody I have met in Vienna and spent worthwhile and enriching time with. And, ladies and gentlemen, dear colleagues thank you to you too for taking the time to listen to/read this "… affectionate, personal review of just on 20 years CHNT participation". It has been a nostalgic pleasure to put it together.

Towards Unleashing the Potential of Elevation Data for Archaeological Research

Reviewing Past and Present Applications

Irmela HERZOG, The Rhineland Commission for Archaeological Monuments and Sites, GERMANY

Abstract: Since the first years, elevation data has played an important role in many contributions presented at the conferences in Vienna. The 25th conference which formerly had the German title “Archäologie und Computer” and now is known as “Cultural Heritage and New Technologies” is the occasion for looking back on early archaeological applications of digital elevation models (DEMs), advances in the course of time, the state of the art and future developments. Many of the approaches presented rely on elevation data grids that are generated from irregularly distributed altitude points. Before the first conference in Vienna, several high-impact papers dealing with elevation data were published. In most cases, their goal was to create predictive models, i.e., to delimit areas of high probability for detecting an archaeological site. Attributes derived from elevation data such as slope, aspect, view quality and shelter were often used as predictor variables. The papers presented at the Vienna conferences are evidence of the fact that archaeological predictive modelling is a highly controversial topic. Additional contributions at the conference in Vienna are revisited that deal with retrodictive modelling, i.e., explaining the distribution of known sites based on landscape properties, with predicting (or retrodicting) the location of linear features such as roads or boundaries, and with issues of low-resolution digital elevation models. Moreover, contributions at the Vienna conference are highlighted that reflect the development of applying high resolution elevation data for detecting archaeological sites. The examples presented are supplemented by some illustrations from the author’s and her colleague’s work in the Rhineland.

Keywords: *Digital Elevation Model—GIS—Lidar Data—ALS Data—Predictive Modelling*

CHNT Reference: Herzog, I. (2022). ‘Towards Unleashing the Potential of Elevation Data for Archaeological Research. Reviewing Past and Present Applications’, in Börner, W., Rohland, H., Kral-Börner, C. and Karner, L. (eds.) *Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020.* Heidelberg: Propylaeum.
doi:10.11588/propylaeum.1045.c14491

Introduction

Looking back at the first conferences on computer applications in archaeology (with the German title “Archäologie und Computer”) held in Vienna, the papers employing complex analysis of elevation data have impressed and inspired the author most. A substantial number of contributions presented in Vienna have dealt with advances in this research area in the course of time irrespective of the fact that the conference changed its name. This paper looks back at the developments before the first conference in Vienna was held and continues to highlight relevant aspects of this topic, nearly all of these were presented at the annual cultural heritage conference in Vienna. The selection of contributions revisited is subjective, and a substantial portion reflects the author’s own work presented in

Vienna or performed at the Rhineland Commission for Archaeological Monuments and Sites in Bonn, Germany. Due to time and funding restrictions, this work mostly relied on elevation data not recorded for archaeological purposes. The main goal of this paper is to give an overview of the state of the art of elevation data processing and lessons learnt, some of which run the risk of oblivion due to the fairly long timespan since their first publication.

Figure 1 presents an overview over the concepts and advances in elevation data use in archaeology. These aspects are discussed in more detail in the chapters below. Figure 1 also illustrates that some concepts evolved with time. For instance, interpolation was at first mainly employed for generating a raster digital elevation model (DEM) from contour line points digitized from paper maps; later, at a different scale, interpolated surfaces were generated from ground points measured by Lidar (light detection and ranging).

The focus of the next section of this paper is on early archaeological applications of elevation data in the 1980s and 1990s. Many attributes derived from elevation data such as slope and aspect were already used in the early papers. These attributes are important building blocks of the first complex GIS application in archaeology, which is known as predictive modelling (PM) and discussed subsequently. The aim of this set of methods applied in cultural heritage management is to delimit areas of high probability for detecting an archaeological site. Potential and limits of PM are discussed, highlighting a paper presented at the Vienna conference in 1999. PM is closely related to retrodictive modelling, i.e., explaining the distribution of known sites based on landscape properties. A paper at the CHNT19 conference applied retrodictive modelling for medieval settlements in a hilly region based on several attributes derived from elevation data. The early PM applications focus on point data. Approaches for predicting (or retrodicting) the location of linear features such as roads or boundaries were presented also at the conferences in Vienna. Another section of this paper discusses issues with elevation data at a scale typically used for landscape analysis. These include generation of elevation data grids from contour line data as well as accuracy and resolution of the point or grid data. The issues are illustrated by examples from the Rhineland and some of the results presented on a poster at CHNT20.

Since 2004, the use of digital elevation data for detecting archaeological features has been an important topic at the Vienna conferences. High-resolution elevation data is required which is mostly recorded by aerial laser scanning (known as ALS or Lidar data). This data gradually became readily available in many European countries. Shallow features require refined visualisation techniques, some of these are exemplified by recent applications from the Rhineland. Finally, the discussions of the previous chapters are summarised and issues with ALS data are reviewed. Although machine learning approaches for analysing elevation data were already presented at the Vienna conference in 2005, these applications have become more widespread only recently (CHNT conference in 2019). Currently, the types of archaeological features that were used as test cases in the machine learning approaches based on ALS data are limited. But in future, this will most probably change, and the author is looking forward to new talks on this topic at future CHNT conferences.

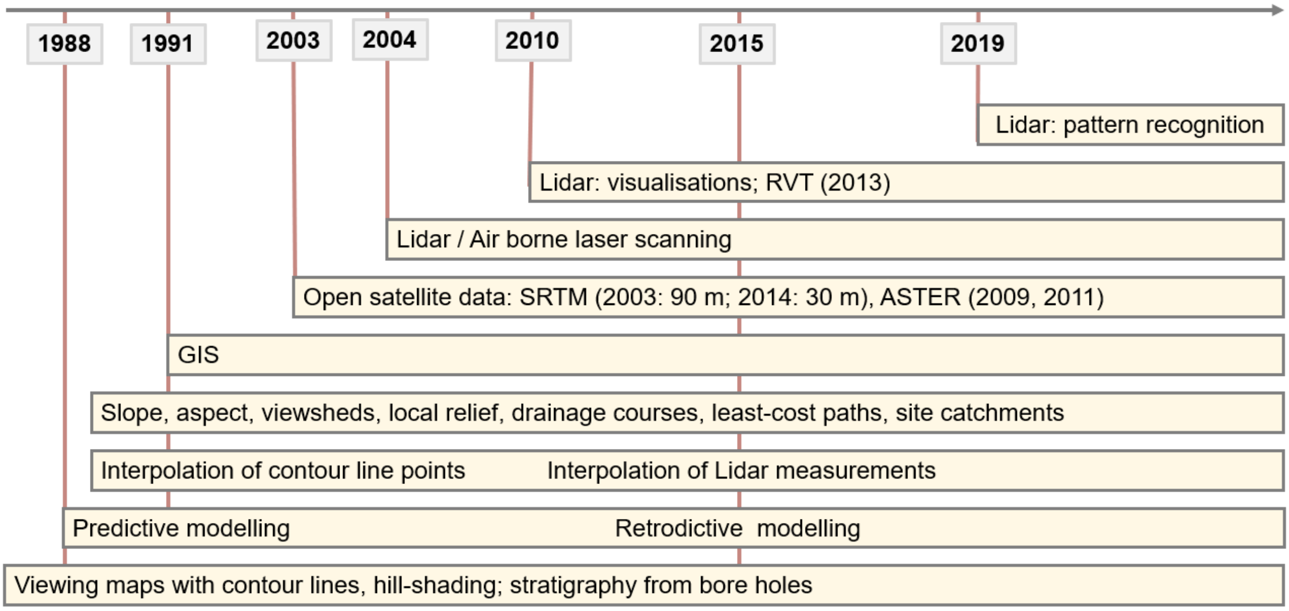


Fig. 1. Timeline: use of elevation data in archaeological research (© Irmela Herzog)

Looking back at the 1980s and 1990s

Before digital elevation data covering large parts of the world at different scales became available, archaeologists used contour lines on analogue maps to identify possible site locations and to assess the risk of erosion for known sites (Fig. 1). These are some of the reasons why scanned maps with contour lines at a scale of 1:25,000 were integrated in an information system with a GIS component for archaeological sites in Saxony, Germany, presented at the Vienna conference in 1998 although more accurate topographic maps without contours were also part of that system (Zeeb, 1999).

An early application of elevation data for archaeological research is presented in the publication by Kvamme (1988). He used elevation data digitized from contour maps in the 1980s with the aim of developing and testing “models of archaeological distributions that have a predictive capacity”. The paper includes descriptions of how to derive slope and aspect from a contour map and mentions two approaches for comparing aspect measurements in view of the 0°=360° issue. Kvamme also presents key figures for measuring local relief, terrain texture, view quality and shelter. Moreover, he refers to the publication by Ericson and Goldstein (1980) for estimating travel time based on slope. So, this paper touched many subjects that are important for state-of-the-art archaeological landscape research in hilly or mountainous terrain today. The use of elevation data for PM became fairly widespread in the years after Kvamme’s publication especially after GIS software became popular.

Kvamme also is an early adopter of GIS software that provides tools for calculating the key figures mentioned above (Kvamme, 1992). After generating a DEM grid based on digitized contour line data, GIS allowed him to generate viewsheds as well as 3D visualisations of the terrain that highlight the location of finds or sites. In his papers, he also suggests a new DEM based approach for identifying drainage courses. The proceedings volume containing Kvamme’s GIS papers also includes a contribution by Gaffney and Stančič (1992) that presents site catchments. These are derived from slope-dependent cost surfaces, i.e., rely on elevation data as well.

Subsequently, archaeologists all over the world have adopted, discussed, or improved these approaches. An example is the PhD thesis by Axel Posluschny (2002), parts of which were presented at the Vienna conference in 1999. The thesis includes several analyses based on data derived from a DEM: preferred ranges of elevation, slope, and aspect are identified for the sites considered; the thesis also discusses site preservation and detection probability depending on the local relief key figure.

Predictive and retrodictive modelling

Posluschny used typical PM approaches, a set of methods “for projecting known patterns or relationships into unknown times or places” (Warren and Asch, 2000), one of the earliest complex applications of elevation data in archaeology (Fig. 1). His main goal was to understand past land use. In cultural heritage management, the aim of PM is to reduce the effort for surveying a complete area by identifying areas that are most likely to contain relevant archaeological remains (Verhagen et al., 2006; Whitley, 2004). As a result, heritage managers, planners and designers are provided with appropriate cartographic tools: “not just maps showing the locations of currently known archaeological sites and monuments, but also maps indicating where to expect archaeological material” (Kamermans et al., 2004).

The early approaches relied on two assumptions: “first, that the settlement choices made by ancient peoples were strongly influenced or conditioned by characteristics of the natural environment; second, that the environmental factors that directly influenced these choices are portrayed, at least indirectly, in modern maps of environmental variation across an area of interest” (Warren and Asch, 2000). Several Dutch researchers applied PM techniques already in the 1990s and presented a discussion of the results as well as approaches for improvement at the CHNT predecessor conference in 1999 (Verhagen et al., 2000). They point out violations of the second assumption of PM techniques outlined by Warren and Asch (2000) due to bias by research intensity and changes of relief and pedology since the period considered as well as post-depositional disturbances. Moreover, they underline the importance of previously existing man-made landscape elements such as roads for choosing a site location for some periods of the past. These attractors are not in accordance with the first assumption of PM approaches as defined by Warren and Asch (2000). Additional issues raised by this group of authors with respect to previous approaches in the Netherlands are lack of temporal resolution and of distinction between site types such as settlements and burials. The progress in this discussion is reflected in two additional papers presented in Vienna in 2003 (Kamermans et al., 2004) and 2005 (Verhagen et al., 2006). The researchers come to the conclusions “that predictive modelling is an issue that is far from ‘solved’”, that “academic and public archaeology in the Netherlands are still opposed when it comes to predictive modelling”, and that these issues could be addressed by providing a measure of the uncertainty for the PM results. The Dutch debate and some contributions by British colleagues (summarised by Wheatley and Gillings, 2002, pp. 179–180) inspired a contribution by the US based archaeologist Thomas Whitley (2004) at the CAA conference held in Vienna in 2003. He observes that PM approaches often achieve success if they are based on “limiting factors on all human behavior; primarily slope and distance to water”.

Although digital elevation data did not play an important role for the early Dutch predictive models due to the mostly level ground in this country, early PM applications in other parts of the world relied partly on elevation data and derivatives thereof (i.e., slope, aspect, indices of ridge/drainage, local relief) as well as on geological and soil data (Wheatley and Gillings, 2002, p. 167). An example is the PM of settlements in a region in the Czech Republic presented at the “Archäologie und Computer” conference in 2002 (Golan, 2003). The issues discussed by the Dutch group are relevant for these predictive models as well. Golan (2003) did not only include elevation, slope, aspect, local relief and shelter quality in his analysis, but also cost distances to water courses, forts, and geological features. Unfortunately, the paper does not give any details on the cost-distance computations, but typically, cost-distances are derived from slope (i.e., from elevation data, see below).

A variant of PM is site location analysis also known as retrodictive modelling, that is explaining the site distribution based on landscape data. Typically, the landscape variables used for retrodictive modelling do not differ from that used for PM. An example of retrodictive modelling for settlements in a rural hilly study area east of the Rhine was presented at the CHNT19 conference (Herzog, 2015). Figure 2 (left) is based on a list of place names that indicates for each settlement the year when it was first mentioned. For the settlements mentioned before 1601 AD, four strong impact variables were identified by retrodictive modelling: soil quality, slope, local prominence and least-cost distance to flow accumulation. The latter three variables were derived from a DEM.

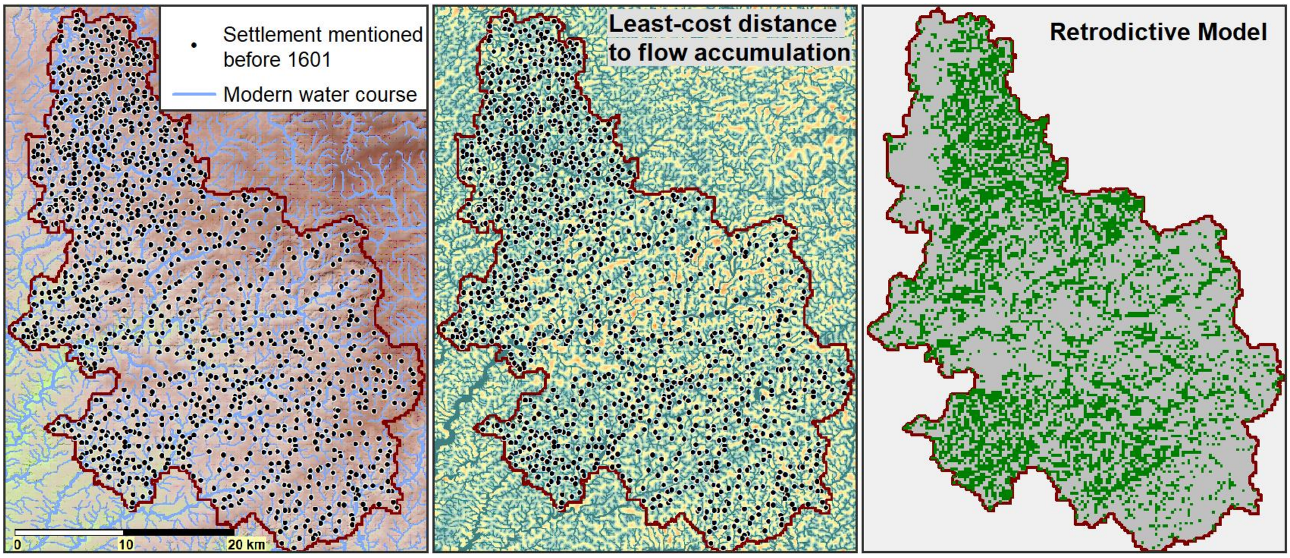


Fig. 2. Left: Study area east of the Rhine with dots representing the settlements mentioned before 1601 AD, background: DEM and water courses; Centre: Least-cost distance to flow accumulation (blue = close to water course); Right: Retrodictive map, green cells with a cell size of 250 m indicate high retrodictive values. (© Irmela Herzog)

Retrodictive modelling based on a complete set of sites (e.g., settlements) also allows assessing the accuracy of PM approaches. This was performed for the case study presented above. The retrodictive model shown on the right in Figure 2 depicts green patches where the four strong impact variables indicate favourable conditions for settlement. According to Warren and Asch (2000), “a successful predictive model is one that minimizes classification errors (site versus nonsite) to such an extent that it offers a substantial gain in accuracy over null models arising from chance alone”. This gain can be assessed by a performance indicator proposed by Kvamme, with values in the range of 0 to 1 (Warren and Asch, 2000; Wheatley and Gillings, 2002, p. 178). Gain values close to 1 indicate high predictive utility. According to Whitley (2004), “a good predictive model should achieve a gain statistic at least above 0.5”. Whereas Wheatley and Gillings (2002, p. 178) refer to a predictive model with a gain of at least 0.8, the gain of the retrodictive model presented in Figure 2 is 0.41. Considering the high settlement density in the study area with hardly any gaps, the latter gain value is probably close to the maximum that can be achieved.

In retrodictive modelling, when all site locations are known, spatial patterns (e.g., minimum distance to the neighbour, adequate farming plots for each farmstead) can be analysed. These patterns as well as the size of settlements are important aspects when reconstructing past landscapes, but including them in a PM approach is a very complex but feasible task (e.g., Bevan and Wilson, 2013).

The predictive and retrodictive models discussed above rely on known sites. In contrast, deductive approaches can derive predictor variables from theoretical considerations (Wheatley and Gillings, 2002, p. 169). An example for such a deductive approach was presented in the best student paper at CHNT24 (Rom et al., 2020). The authors of this paper assume that the sites in their study area in Lebanon can be found on hilltops with a certain size and circularity. The site candidates were identified using elevation data recorded in the course of the project. Aerial photographs were used to validate site candidates.

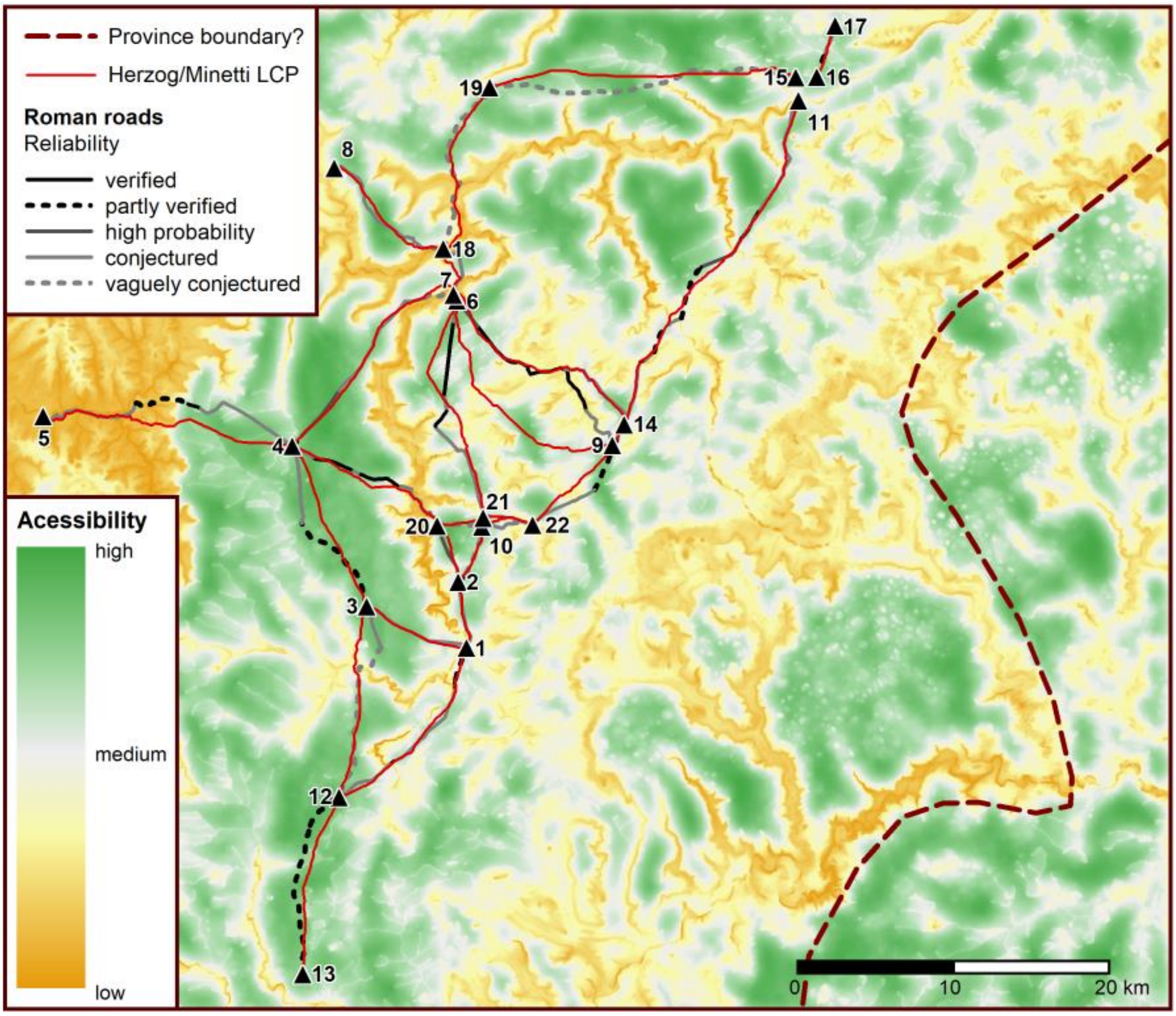


Fig. 3. Roman roads, classified according to reliability, reconstructions by least-cost paths (LCP) and a hypothetical boundary. Background: Accessibility map for cost function Herzog/Minetti (© Irmela Herzog and Sandra Schröer)

In the early days of PM, the extent of the site was not considered, instead the analysis relied mainly on point data (e.g. Golan, 2003; Warren and Asch, 2000). Obviously, this is not appropriate for linear features such as roads, water pipelines or boundaries, which is illustrated by the case study by Münch (2007) presented at the Vienna conference in 2006.

Least-cost path (LCP) computations are frequently applied in order to reconstruct past routes. The cost function typically depends on slope, sometimes combined with other factors such as viewsheds or water courses. As mentioned above, the computation of viewsheds and of likely water courses (by flow accumulation algorithms) are also based on elevation data. Since the first least-cost approaches (e.g. Gaffney and Stančič, 1992), the number of slope-dependent functions applied for reconstructing paths and roads has increased considerably, and some of them require the selection of parameter values. For instance, the poster by Herzog and Schröer, presented at CHNT 22, (paper published in 2019) tested four slope-dependent functions for walkers and another function for vehicles that has a critical slope parameter (three critical slope values were tested). The aim was to reconstruct a set of Roman roads in southern Germany. Figure 3 shows the result of the most successful reconstruction of the roads by LCPs.

For reconstructing the boundaries of a site, site catchments relying on a cost surface are often applied. Most of these cost surfaces are derived by attributing costs to slope. An early example by Gaffney and Stančič (1992) was mentioned above. Thiessen polygons have been used for reconstructing boundaries based on the assumption that there is no empty space between the territories considered (Conolly and Lake, 2006, p. 211). Slope-dependent least-cost variants of Thiessen polygons were computed by Herzog and Schröer (2019), the centres are probable Roman capitals of administrative units in southern Germany. Figure 3 shows another approach for identifying possible boundary locations: boundaries are mostly found close to low accessibility areas. The accessibility map in Figure 3 was also computed using elevation data, details of this approach can be found in the publication by Herzog and Schröer (2019).

Issues with elevation data

Several archaeologists in Germany admired advances in PM in the Netherlands and other countries in the 1990s and considered starting similar projects. Being aware of the substantial landscape change in the Rhineland area due to human impact including open-cast mining, other mining activities, motorways, quarries and dams, two projects were initiated in the Rhineland with the aim of investigating the reliability of the altitude information on maps that were created before most of these landscape modifications had taken place.

In the first project, Lechterbeck (2008) compared the DEM derived from contour lines on maps created in the late 19th century (scale ca. 1:25,000) with that of a DEM with a grid size of 10 m based on Lidar and photogrammetric data acquisition. Only part of the differences in elevation could be attributed to anthropogenic impacts. In forested areas, visibility was restricted, this impeded elevation measurements using the technologies available in the 19th century ensuing substantial errors. Therefore, the elevation data on the late 19th century map set is at best useful in areas of agricultural use at the time of map making.

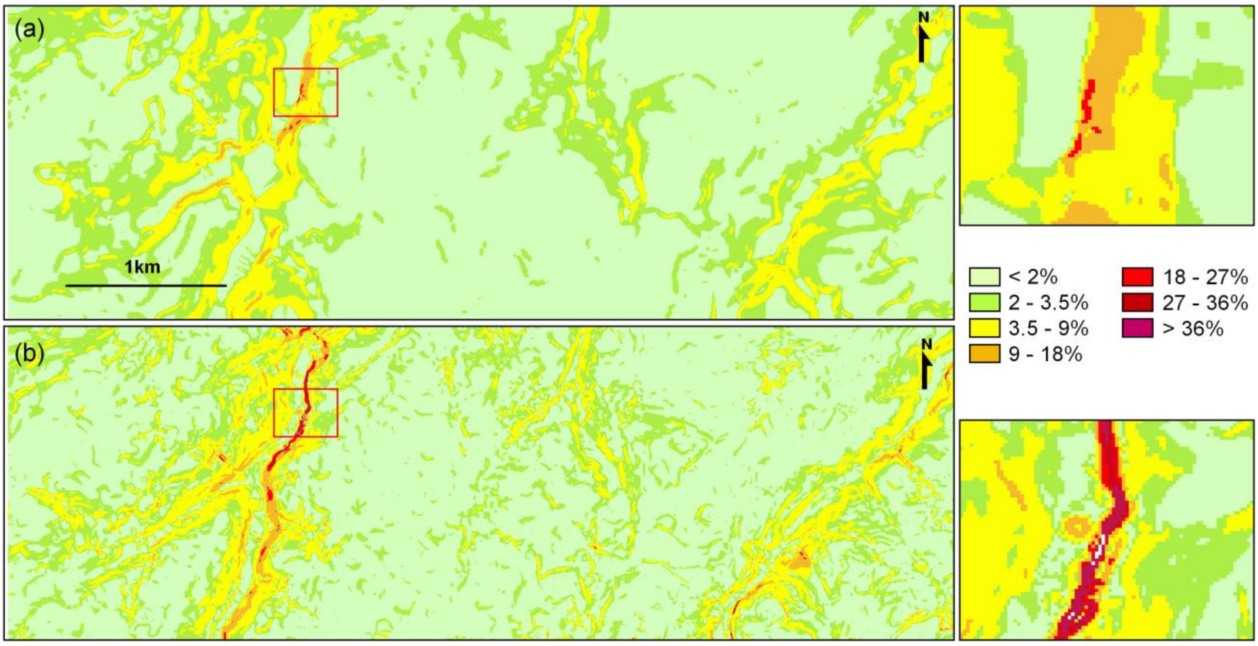


Fig. 4. Slope maps for the Merzbachtal, west of the Rhine in the Rhineland. (a) derived from contour lines on late 19th century maps at a scale of 1:25,000, (b) based on contour line maps at a scale of 1:5000 created in 1955. (© Irmela Herzog and Ana Judith Largo Arias Marek based on geodata provided by Geobasis NRW)

The aim of the second project by Herzog and Largo Arias Marek (2009) was to reconstruct the old surface in areas of open-cast mining west of the River Rhine. Due to the known issues with the late 19th century maps, contour line maps at a scale of 1:5000 created in 1955 were purchased from the ordnance survey institution in the Rhineland (Geobasis NRW). The contour lines were digitized semi-automatically and raster DEMs created from this data. Unfortunately, the 1:5000 contour line maps were not available for all parts of the study area. Therefore, the 1:5000 DEMs were compared to those derived from the late 19th century maps, hoping for limited errors in the study area where agriculture prevailed at the time when the maps were created.

The differences in elevation were acceptable in the study area (mean: 1.07 m). But due to the differences in scale, the DEM derived from the late 19th century maps is smoother. This has a dramatic effect on the slope maps derived from the two DEMs (Fig. 4). The classification of slopes in Figure 4 is based on a scheme for agricultural use. The slope map of the smoothed DEM (Fig. 4a) indicates a larger proportion of arable land than the slope map in Figure 4b.

A similar effect can be observed when reducing the resolution of a DEM due to computational load in a large study area. A case study in the highlands of Ecuador by Herzog and Yépez (2016) presented at CHNT20 compared SRTM 3” (grid size ca. 90 m) and SRTM 1” (grid size ca. 30 m), these are two freely available DEMs based on satellite measurements. Table 1 shows the distribution of the slope values of the two DEMs for the study region considered. In this region with steep slopes, the slope of half of the terrain exceeds 44.8% when slope is derived from SRTM 1” data; for the slopes derived from the SRTM 3” DEM, this median value is considerably lower (37.2%).

Table 1. Differences in the distribution of the slope values (in percent) for the two SRTM elevation grids

DEM	**1st quartile (25%)**	**Median (50%)**	**3rd quartile (75%)**
SRTM 1”	27.6	44.8	64.0
SRTM 3”	23.7	37.2	53.1

As mentioned above, contour line data is an alternative to freely available satellite data in many cases, for instance if working with old maps or if the contour lines provide a higher accuracy. In the case study by Herzog and Yépez (2016), the digitised contour lines of the official 1:50,000 maps provided by the Military Geographical Institute of Ecuador resulted in a more accurate DEM than the satellite data. Typically, DEMs derived from contour line data exhibit spikes in the histogram of altitudes and 'tiger-striping' of the slope map (Conolly and Lake, 2006, p. 105; Wheatley and Gillings, 2002, pp. 116–119). Filters resulting in a smoothed DEM may remove most of these unwanted effects; but as mentioned above, smoothing will no longer show abrupt changes in slope and underestimate a considerable portion of the slopes.

Landscape surface modifications are not only caused by bulk material extraction at a large scale, building projects, and erosion. Verhagen et al. (2000) describe changes in the relief of the Netherlands due layers of peat dating to the Medieval period. In some areas, the peat layers were exploited for fuel in the Late Middle Ages and later, resulting in substantial variations in the depth of the soil layer covering earlier remains.

DEMs for detecting archaeological features

The resolution of a DEM is vital for the detection of archaeological features. At the CAA conference in Vienna in 2003, Beex (2004) pointed out that the Nyquist limit determines the minimum size of features to be detected on the DEM surface: to identify a circular pit with a diameter of 20 m in a DEM, the maximum distance within the set of altitude points forming the basis of the DEM should not exceed 10 m, and 5 m is the recommended maximum distance. Interpolation of irregularly distributed elevation points resulting in a high-resolution DEM grid may obscure large gaps in the set of elevation points. These issues are also relevant for ALS data as outlined below.

At the 9th conference "Archäologie und Computer" in 2004, two papers focused on the detection of archaeological features based on elevation data. The contribution by Gerlach et al. (published in 2008) used a fairly coarse DEM with a grid size of 10 m to detect the remains of large bulk material extraction pits, that were partly refilled. A large proportion of these pits were created by the brickmaking industry and its precursors. The earliest brickearth pits are of Roman origin, but most of these features date in the 19th and early 20th century. These brickyards were clustered in the western part of the Rhineland. As most pits were nearly completely refilled, it was hardly possible to detect them in the field. DEM visualisations by colour-gradients depicting altitude change or by contour line plots proved not very useful for identifying the pits in non-level areas. Hill-shading visualisations were more successful (Fig. 5). Artificial cross sections allowed assessing the depth of these features, which often did not exceed 1 m for a former pit with a diameter of about 50 m (Fig. 5). These pits are important because they often had (partly) destroyed archaeological features dating back to earlier periods. Moreover, the material in the pits had been relocated and the refill material probably originated from somewhere else. Consequently, the prehistoric finds identified during field walking are not a reliable indicator of a prehistoric site, if the soil including the finds was transported to this location for pit refilling purposes. Many earlier archaeological features can be detected by similar approaches using DEM grids with higher resolution.

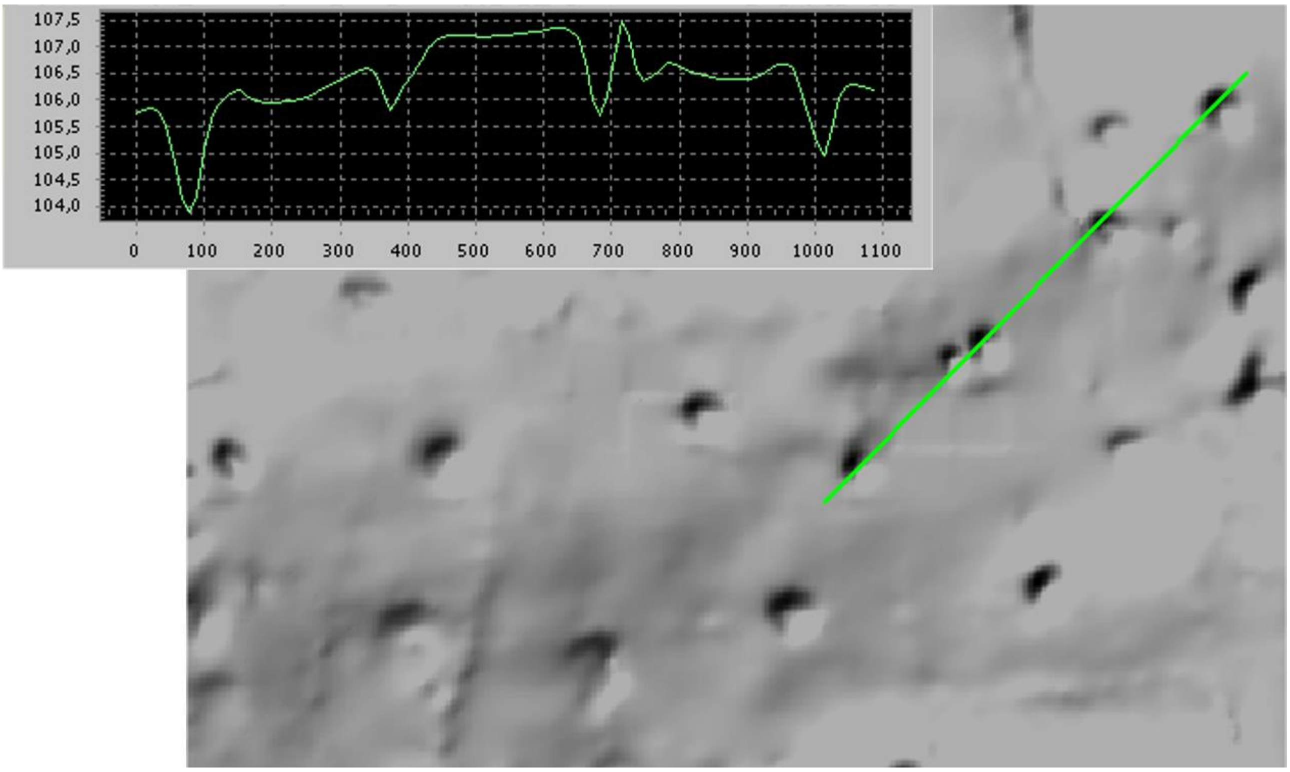


Fig. 5. Visualisation by relief shading of partly refilled brickearth pits, west of the Rhine (© Irmela Herzog and Renate Gerlach based on geodata provided by Geobasis NRW)

In many countries, the resolution of available elevation data increased considerably in the course of the last two decades partly due to new photogrammetric technologies (Structure from Motion, SfM) but mainly due to ALS adopted by many ordnance survey institutions. Initially, the ALS point density was only 1 measurement in 36 m² in forests (Zijverden and Laan, 2005), but nowadays about 19 ground points per m² can be achieved in such areas (Fig. 7: DEM 2015).

Zijverden and Laan (2005) introduced archaeological survey by ALS data visualisations to the Vienna conference in 2004. Their case study in the Netherlands used data that was made available in that year for the first time. They discuss the visualisation approach “hill-shading from different directions”. Simple hill-shading with varying parameters (vertical exaggeration, position and azimuth of the light) was also applied by Kosian (2008) at the CHNT conference in 2007. He discusses the detection and recording of field systems known as Celtic Fields (that in fact date from late Bronze Age, Iron Age into the early Roman era) in the Netherlands using elevation data with a grid size of 5 m provided by the Dutch ordnance survey agency. Remains of these field systems were also identified in the Rhineland where they are heavily eroded. Refined visualisation techniques are required to enhance the recognizability of these remains. Different visualisation techniques have been developed for ALS data and are implemented in free software (Hesse, 2010; Kokalj and Somrak, 2019; Zakšek et al., 2011). Two examples from the Rhineland are presented in the next chapter.

However, it is important to take the limits of ALS data for archaeological feature detection into account. Beex (2017) lists five issues on a poster presented at the CHNT21 conference:

- Most ALS data includes gaps that may obscure the presence of archaeological features;
- ALS data is often provided with automatic or semi-automatic classification of point data which is not perfect: archaeological features classified as (modern) built structures may be missing in the ground point set;
- the minimum size of features that can be detected depends on the ground point density (Nyquist limit, see above);
- the interpolation algorithms used for computing raster grids from the set of irregularly distributed ground points have limitations; and
- field validation of the results is required.

Recent applications of elevation data in the Rhineland

The situation in the Rhineland may appear like elevation data paradise for many colleagues: the ordnance survey institution Geobasis NRW provides open access ALS data with classified point data in laz format. Moreover, interpolated raster data with a cell size of 1 m is available, as well as four WMS layers providing grey and colour hill-shading of the 1 m DEM from two different directions. But there are also some drawbacks: the data is updated at regular intervals of about five years, and the old versions are no longer accessible online. The flight dates of all currently online available ALS data sets are provided in a separate metadata table, that should be downloaded when downloading the ALS data.

In Figure 6, two ALS data visualisations of a site in the forest near Lindlar-Scheel are shown. The aims of the ALS data analysis were: correctly delimiting and recording the site and its features as well as a nice presentation for the public. In Lindlar-Scheel, a ruin of the tower and some walls are still visible today. Therefore, the corresponding elevation points were classified as non-ground points in the ordnance survey data. To give the full picture, the points on the ruin and the walls had to be selected from the set of non-ground points, that also included a large number of points on trees. Thematic maps of the elevations assisted in the manual selection process. One of the most popular visualisation techniques is local relief model (Hesse, 2010) which highlights local elevations and depressions. Figure 6a shows an example of this approach combined with low-contrast hill-shading: depressions such as the ditch surrounding the castle are shown in green, elevated areas in yellow.

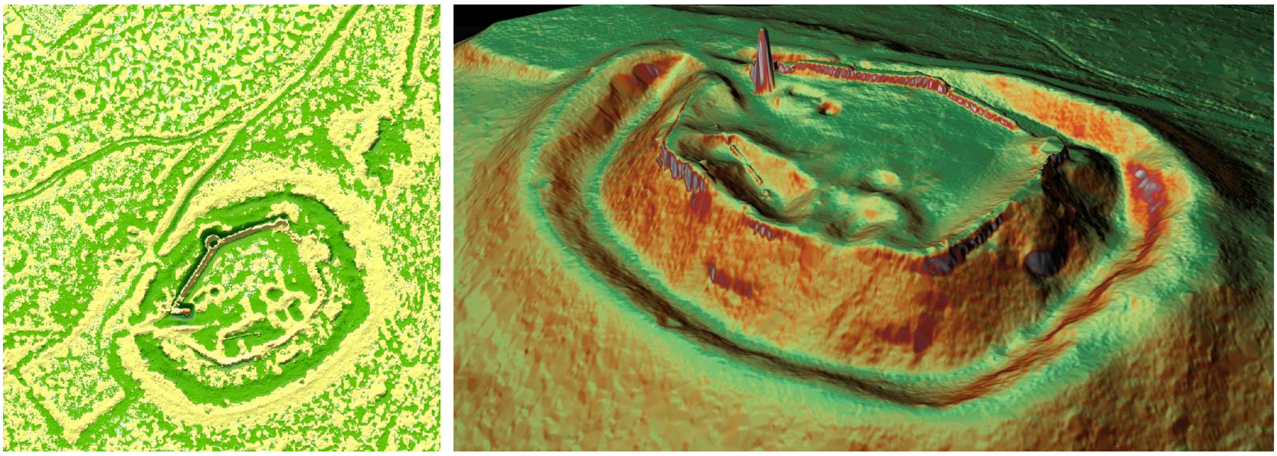

a b

Fig. 6. Visualisations of ALS data depicting the remains of a castle known as Neuenberg a) local relief model; b) 3D view created by Planlauf/terrain (© Irmela Herzog based on data provided by Geobasis NRW)

The 3D visualisation in Figure 6b created by the Planlauf/terrain software benefits greatly from a colour scheme that depends on the slope values. Planlauf/terrain (https://planlaufterrain.com/) is a low-cost Windows application that 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 landscape feature. Films created by Planlauf/terrain are attractive assets for presenting a site mostly hidden by trees to the public.

A master thesis is currently in preparation with the aim of analysing prehistoric fortifications east of the Rhine by GIS methods. The preliminary list of sites consists of 41 entries, one of these is a likely earlier site at the Neuenburg location. High resolution (20 cm) DEMs have been derived from the irregularly spaced ALS data for relevant areas surrounding the sites. In a next step the sites were delimited as precisely as possible, and the remains of the ramparts were digitized. This allows comparing many features of the sites such as the area enclosed by the fortification, the current size of the ramparts, the slope of the surrounding area, and the shape. The aim is to derive a classification of the sites. A lower resolution (25 m) DEM is the basis of investigations into possibilities of communication between the fortifications either by signals or by routes. First results have already been published (Rung and Herzog, 2021).

Figure 7 illustrates the potential of ALS data sets from different years for monitoring sites. The ALS visualisations in the centre of Figure 7 use a colour gradient for elevation combined with hill-shading for visualising a protected site in Oberhausen. The late Medieval or early modern site consisted initially of ramparts and ditches.

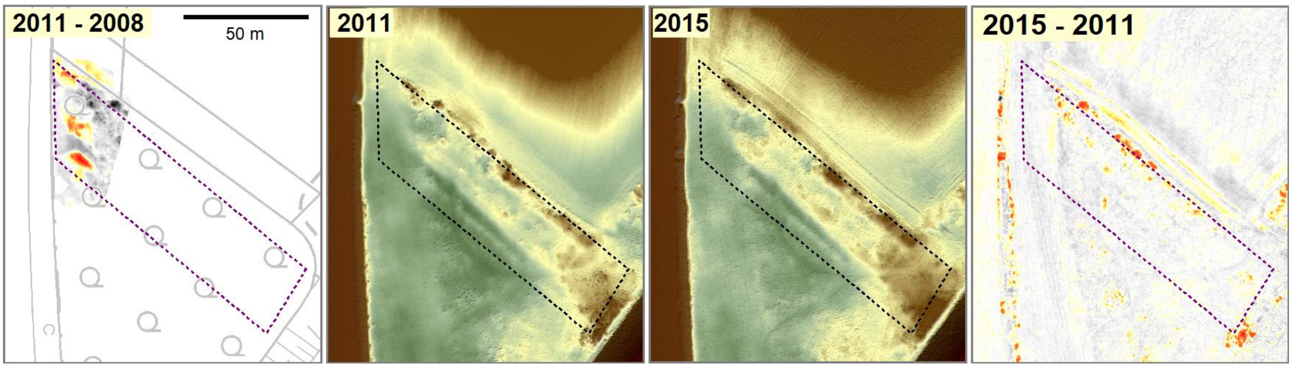


Fig. 7. The dotted line delimits a protected site, i.e., remains of a feature consisting of ramparts and ditches. The elevations of the western part of the site were surveyed manually in 2008 (739 measurements), the image on the left shows the difference to the DEM that was computed from ALS data recorded in February 2011. The red area highlights an elevation minus of about 40 cm. Hill-shading of the DEMs based on the 2011 and 2015 ALS data are depicted in the two centre images. The differences between these two DEMs are shown on the right. (© Irmela Herzog based on data provided by Geobasis NRW)

The DEM dated 2015 was downloaded in September 2019. The earlier DEM dated February, 2011 was delivered as a special favour to the Rhineland Commission for Archaeological Monuments and Sites in 2012, when this data was not yet free of charge. At that time, metadata was provided as well. After the CHNT25 conference, the elevation data recorded in March 2020 became available for download as well.

Figure 7 (left and right images) shows the results of subtracting two DEMs with the aim of identifying areas where the site was modified. On the left, the DEM generated from ordnance survey data recorded in 2011 is subtracted from the DEM based on manual altitude measurements performed in 2008 by an archaeological firm in advance of construction activities for a pipeline. Areas of material removal are highlighted in red, additions are shown in black. The resulting image shows that in the western part of the site, the ramparts were partly destroyed after the manual altitude measurements were taken in 2008.

Before computing the differences between the two ALS DEMs from 2011 and 2015, these DEMs had to be adjusted in elevation and position. Elevation data on the motorway—which is partly visible in the western part of the images in Figure 7—was used for assessing the difference in elevation. Artificial sections in north-south and east-west directions helped to assess possible displacements in these directions. The resulting image shows that in the time interval between 2011 and 2015, areas of removal are mainly located at or beyond the boundary of the site (Fig. 7, right). A more detailed analysis of the relief of the site presented in Figure 7 taking the elevation data recorded in March 2020 into account has been published (Herzog, 2021).

A similar approach for correcting horizontal and/or vertical displacement is discussed in the contribution by Herzog and Yépez (2016) presented at the CHNT20 conference. At this conference, another case study by Hesse (2016) introduced a systematic search for these offsets in ALS data in southern Germany.

Conclusions and Discussion

Elevation data provides the basis for most archaeological landscape analysis approaches and for detecting features in ALS data. In many countries it is no longer necessary to digitize contour maps, because high quality elevation data is freely available. In countries without such services, case studies in landscape archaeology often rely on satellite data with limited accuracy and resolution or on elevation points on digitized contour lines (Herzog and Yépez, 2016).

The main focus of this paper is on reusing elevation data recorded for non-archaeological purposes. An alternative is to instigate an aerial laser scanning project (e.g., Rom et al., 2020 at CHNT24) or in sparsely vegetated areas to use SfM. The potential and limits of SfM approaches for generating elevation data are summarised by Hesse (2016). In densely vegetated areas, processing ALS data for ground point identification is far from trivial as exemplified in a case study in Japan presented at CHNT24 (Herzog et al., 2021). Terrestrial laser scanning has also been used for recording elevation data as well as for recording excavation results. The contribution by Fichtmüller and Wollmann (2006) at the Vienna conference in 2005 was one of the first to discuss this technology.

When working with grid elevation data derived from irregularly spaced altitude measurements, the grid size of the raster DEM might be well below the largest gaps in the point cloud. Therefore, checking the Nyquist limit (Beex, 2004; 2017) with respect to DEM grid size might not produce a reliable result. Local large gaps in the point cloud may obscure archaeological features in this area. For creating a raster DEM from a set of irregularly distributed spot measurements or points on a contour line, an interpolation method must be chosen. The potential and limitations of different interpolation methods are discussed for instance in the contribution by Zijverden and Laan (2005) at the CHNT conference in 2004 and in text books on GIS applications in archaeology (Conolly and Lake, 2006, pp. 90–111; Wheatley and Gillings, 2002, pp. 114–119). Interpolation is also required if the raster DEM contains voids. This issue and other issues for instance with water bodies and coast lines were addressed by Kokalj et al. (2006) at the 10th conference in Vienna when presenting an application based on the freely available SRTM altitude data.

A substantial drawback of modern DEM data is the fact that the surface might have changed dramatically since the period considered. The work by Lechterbeck (2008) showed that contour lines on maps created more than 100 years ago might not provide reliable elevation data. Sometimes, surface reconstruction from bore hole data is applied (e.g., Golan, 2003; Zijverden and Laan, 2005). In this situation, the density of the bore holes determines the true resolution of the DEM. In the case study by Golan (2003), this is only about 1 bore hole per 1.3 hectare. As the average slope usually depends on the resolution of the DEM, this is vital knowledge for any slope-dependent analysis such as least-cost path or erosion computations.

Low resolution DEMs (grid size 10 to 100 m) are often applied in archaeological landscape analysis such as retrodictive modelling. This does not only reduce computational load but also reduces the impact of modern landscape modifications at a small scale by introducing some blur effect. It might turn out quite cumbersome to generate such a low resolution DEM from a DEM with a cell size of 1 m. For detecting large features such as the remains of bulk material extraction pits, medium resolution DEMs proved most effective in the Rhineland. In higher resolution DEMs small-scale features are more prominent and obscure larger structures.

Another tedious job is to search ALS visualisations of large areas with the aim of detecting archaeological features. Often, it is quite difficult to identify such features reliably in ALS data because they are partly destroyed or hidden by very dense vegetation. Therefore, two researchers may identify different features in the same study area. For a newcomer to this field, checking the feature candidates against known sites is a viable option for improving reliability. This is imitated by machine learning algorithms that are increasingly applied in recent years. Several approaches for selected archaeological feature types were presented at the CHNT24 conference (e.g., Kazimi et al., 2021). Machine learning applications based on DEMs and attributes derived thereof have been used before. For instance, Deravignone and Macci (2006) presented an Artificial Neural Network for PM of castle locations in the Tuscany region, Italy. They underline the computational load when dealing with high resolution DEMs and large study areas. Nowadays, more efficient and freely available implementations of machine learning algorithms as well as hardware improvements allow faster processing. Therefore, it is expected that machine learning applications will become more popular in many archaeological studies dealing with elevation data.

After acquiring the elevation data for a single site or landscape analysis, processing and visualisation are nearly always fun and provide not only nice pictures but also new insights. The future of CHNT will hopefully see the results of many nice applications of elevation data as well as the development of new technologies for analysing this data.

Acknowledgements

Congratulations for 25 successful conferences on new technologies in cultural heritage to the conference organisers in Vienna. Special, heartful, warmest, and sincere thanks go to Wolfgang Börner, who is the most important person at the Vienna conferences, and who is heart and soul of the conference, warmly welcoming both newcomers and attendees of previous conferences. Moreover, sincere thanks to the Börner family (mainly Andrea and Christina) who assisted greatly in creating this unparalleled atmosphere though they mostly remained in the background. Sincere thanks to Susanne Uhlirz, who did a great job in the CHNT organizing committee and the editorial board of the conference proceedings. With gratitude the former boss of the Urban Archaeology Department in Vienna, Ortolf Harl, is remembered not only because he always had a question after a talk if nobody else had one. Thanks are due to all other staff members of the Urban Archaeology Department, who supported the conference in various ways. To conclude, thanks are extended to Ulrike Herbig and Irmengard Mayer from ICOMOS/Austria, who made sure that the annual CHNT conference will be held in Vienna in future as well.

Finally, sincere apologies for any relevant omissions: due to the large number of contributions presented at the Vienna conferences dealing with elevation data, it is more than probable that several important contributions have skipped the author’s notice.

Funding

This paper was written during spare time, without funding. Work for the projects dealing with elevation data in the Rhineland and referred to in this paper was partly done during office hours at the Rhineland Commission for Archaeological Monuments and Sites in Bonn, Germany. Spare time without funding was used for the author’s collaborative projects located in other parts of Germany or the world. The author benefited from invitations to present her unpaid work at different places, including London, Cambridge, Gaeta/Italy, Innsbruck/Austria, Bamberg, Heidelberg, Berlin, Kiel, Bensberg, and Cologne.

Conflict of Interests Disclosure

The author declares no conflict of interests, except for invitations to give talks (see above).

Author Contributions

This paper mainly gives an overview over projects that were published previously. Details on the contributions to these projects can be found in the referenced publications.

Writing – original draft / review & editing: Irmela Herzog

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Session:
Image-based 3D Documentation Aerial and Underwater

Marco BLOCK-BERLITZ | Martin OCZIPKA | Hendrik ROHLAND

Call

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Keywords: *Image-Based 3D-Reconstruction—Photogrammetry—Sfm—Aerial—Maritime*

Image-based 3D reconstruction is becoming one of the standard tools used in archaeological excavations above and underwater. Nevertheless, standardised workflows, established methods for the assurance of data-quality 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 want to talk about practical solutions and showcase current tools in the field of image-based 3D reconstruction. We are both interested in platforms like UAVs and UUVs for the collection of image data and also in software tools for the processing, storage, retrieval and analysis of 3D-data.

Focussing on key aspects of managing surveys, this session invites 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
- data management solutions for recorded data, integration of 3D data with qualitative data and long-term accessibility of 3D data
- georeferencing and quality assurance
- innovative applications for the analysis of 3D data for archaeological research questions

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

Mini-UUV Cousteau II: Automated georeferencing of real-time 3D models from ORB-SLAM

Suitable for underwater scenarios using indirect GPS information

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Abstract: The semi-autonomous control of the BlueRov2-based mini-submarine Cousteau II uses ORB-SLAM's real-time 3D reconstruction pipeline. Since the point clouds obtained by ORB-SLAM have only a relative reference, an automatic, indirect georeferencing method was developed for a complete mapping in UTM coordinates. Since the mini-submarine communicates with the base via a radio link, the method uses the GPS in-formation available in the buoy and derives the position and orientation of the mini-submarine from the current movement patterns and dive depths. The Cousteau II mini submarine is equipped with a downward looking sonar and an camera. The sonar is used to measure the distance to the bottom and the camera is used to obtain a 3D point cloud of the surroundings. The process starts by calibrating the position of the mini submarine with respect to the buoy. This is done by fitting a circle to the points observed by the mini submarine during a short calibration dive. The position of the mini-submarine is then estimated from the current location of the buoy and the orientation of the mini-submarine is estimated from the heading of the buoy. The estimated position and orientation of the mini-submarine are used to georeference the point clouds obtained by ORB-SLAM. This method is described in detail in the following paper.

Keywords: *Semi-Autonomous UUV—3D Reconstruction—Georeferencing Underwater—Self-Localization—UTM Coordinates*

CHNT Reference: Bommhardt-Richter, M., Block-Berlitz, M., and Brüll, V. (2022). 'Mini-UUV Cousteau II: Automatically georeferencing real-time 3D models from ORB-SLAM, in Börner, W., Rohland, H., Kral-Börner, C. and Karner, L. (eds.) *Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020.* Heidelberg: Propylaeum.
doi:10.11588/propylaeum.1045.c14493

Motivation and Introduction

The development of camera technology into high-resolution, compact, handy, and inexpensive devices has reached a high standard in recent years. Some of these cameras can be used in underwater applications. From videos and single image recordings, realistic 3D models can be reliably reconstructed by Structure-from-motion (SfM) methods (Pruno et al., 2015). Automated planning software is already available for multicopter applications (Block et al., 2018a). The costs for the combination of a multicopter with integrated camera and the corresponding free software for mission planning are far below 1000 Euros. There is currently no comparable solution in the underwater domain that allows automated, cost-effective underwater documentation. Indeed, some systems could perform such tasks at much higher costs (Yang et al., 2019).

However, due to the high price and partly also the actual size of the device, they are not suitable for every application. Especially in the underwater area, where the documentation method is still complicated and expensive (Moisan et al., 2015), the use of videogrammetry offers excellent advantages due to the low hardware usage and the flexibility and robustness of the method (Gehmlich and Block, 2015).

Within the framework of the SMWK-funded research project “Archaeonomous”, Manio, an unmanned underwater vehicle (UUV) has already been successfully developed, which can reliably record smaller underwater areas in an archaeological context semi-autonomously with various camera systems (see Fig. 1, left) (Block et al., 2018b; Bommhardt-Richter et al., 2018, Block et al., 2018c).

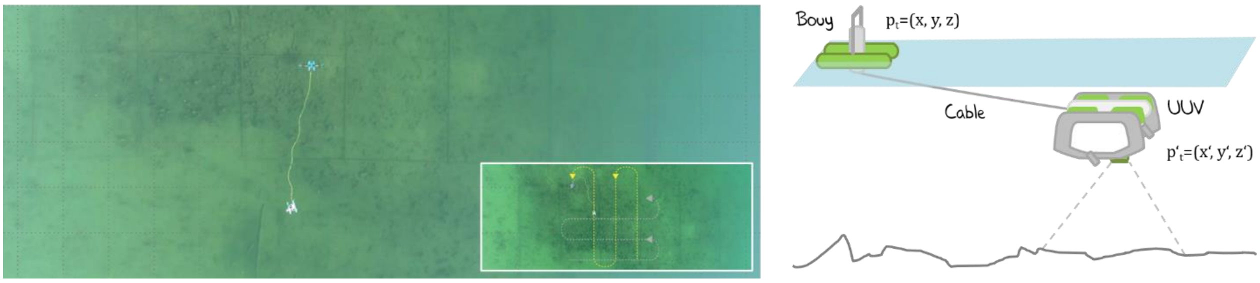


Fig. 1. Left: The Manio mini-submarine system was developed to record underwater areas in an archaeological context with cameras for later videogrammetric 3D reconstruction. For the base, a BlueROV2 was used, which was equipped with additional arms for the attachment of diving lamps and cameras and a self-developed radio buoy. Here we see Manio taking videos of a UNESCO World Heritage Site in Mondsee/Austria 2018 Right: The idea of automatic georeferencing is based on the simple idea that in a favourable situation during the recording, when the mini-submarine (UUV) is continuously moving in one direction for a particular time, the position from the buoy equipped with a GPS receiver can be used. These positions are given an exceptionally high weighting and stored accordingly. Based on the used and known cable length and the diving depth determined by the mini-submarine, the position and orientation of the UUV can be derived underwater. © Authors.

The automatic georeferencing is an important milestone in the localization of the surveyed underwater models, as GPS reception underwater is not directly possible. The idea presented in this article, an indirect solution is based on the positional relationship between the mini-submarine and the buoy at a constant speed (see Fig. 1, right).

The article is structured as follows: Section 2 introduces the theory and related work. Here the problems of georeferencing underwater and the current mini-submarine setup are explained. Section 3 introduces the method for indirect position determination, where selected keyframes are identified and then used for a transformation in UTM coordinates. In section 4, the first experiments and evaluations are presented.

Theory and related work

Reliable underwater georeferencing is still one of the biggest challenges in the 3D reconstruction of underwater areas. A solution, based on the indirect use of GPS information above water, and the structure of the current underwater system are briefly described below.

Georeferencing in underwater scenarios

Underwater georeferencing is still a challenge since underwater GPS data cannot be received directly. Long waves are the only electromagnetic waves that can propagate in water to a certain depth

(Tipler and Mosca, 2007). In the mini-submarine sector, therefore, only long waves with a shallow frequency of less than 30 kHz are used (Farr et al., 2010). Since GPS signals are emitted in the frequency spectrum above 1000 MHz, self-localization underwater is therefore only possible with indirect solutions.

For example, a GPS position measured above water can be derived from the position underwater by means of a stick (the length of which is known) (Scholz et al., 2016). Many different solutions were also developed and investigated in the Archaeonautic project (Block et al., 2018a).

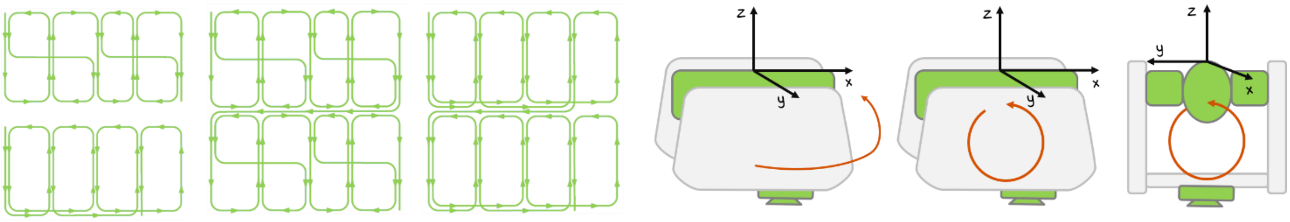


Fig. 2. Left: Here, different recording strategies can be seen, which have a high degree of potential loop closures and are based on classical recording strategies with multicopters (Wittchen 2017). Right: This figure shows the different measurable orientations of the mini-submarine along the respective coordinate axes. On the left, the yaw along the Z-axis is shown, which is particularly relevant for the determination of a straight track on the X/Y-plane. In the middle, is the rotation along the Y-axis, which may indicate a change in the diving depth. On the right, rolling represents the rotation along the X-axis. © Authors.

Real-time 3D reconstruction underwater

Real-time 3D reconstruction using Simultaneous Localization and Mapping (SLAM) provides a promising approach to solve the localization problem [8, 10]. The resulting point clouds can provide first information about the positioning underwater and the driven distances. Since the method depends on the detection of loop closures to minimize the error rate, the acquisition strategy must be designed accordingly (see Fig. 2, left) (Wittchen, 2017).

ORB-SLAM3 is used for real-time 3D reconstruction in the mini-submarine Cousteau-II (Campos et al., 2020). As an extension to the previous version ORB-SLAM2 (Mur-Artal, 2017), the ATLAS algorithm was developed for the management and manipulation of the generated point clouds and maps. As soon as the tracking is lost, the keyframes recorded up to that point are regarded as a separate sub-map, which is stored in the ATLAS (Elvira et al., 2020). During the next initialization, a new submap is created. If similarities between the features of different sub-maps are recognized, they are combined to a common map. Furthermore, ORB-SLAM3 now offers several camera models, which makes pre-calibration and distortion correction necessary (Block, 2020).

The processing chain in the UUV starts with images with the reduced resolution of 432 × 420 pixels by a GoPro Hero 4 BE as input for ORB-SLAM3 and takes a resolution of 1080p for the later video-based 3D reconstruction in Archaeo3D (Block et al., 2018c).

2.3 Camera calibration and automatic image enhancement

For the single images captured by the underwater cameras, which are extracted from the videos, the distortions must first be corrected. This is done once by a camera calibration step with the selected camera and resolution setup (Block, 2020).

For further processing of the underwater images, it is beneficial to send the images through an automated color adjustment and image enhancement process. With the help of the JEnhancer (Block et al., 2017A) and JFeatureManager (Block et al., 2017B) modules, the number of features identified is significantly increased, which is necessary for the reduced 1080p capture strategy and the partly low-contrast underwater shots. The further 3D reconstruction steps in COLMAP (Schönberger and Frahm, 2016) or VisualSFM (Wu, 2013) thus provide significantly better results.

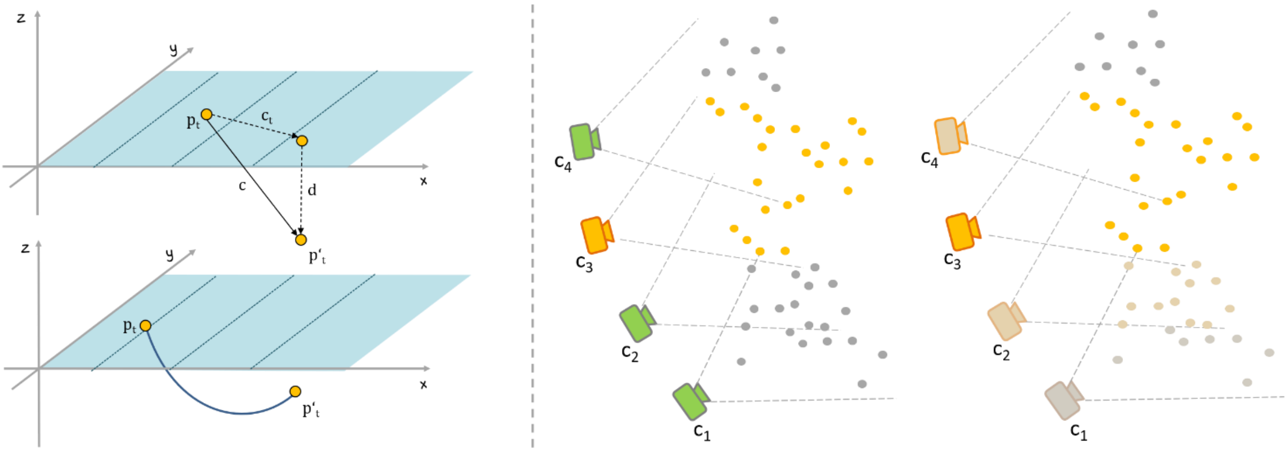


Fig. 3. Left above: The figure shows the model used for georeferencing. This describes an ideal application case in which the mini-submarine travels long enough at a constant speed in one direction to stretch the cable between the buoy and the UUV tight. Thus, the cable can be assumed to be a straight line between the two positions. Left below: Here, we see an alternative view where the cable is sagging in a resting state. This case can be better described with the catenary curve/model. Center/Right: The figure shows two examples of keyframe weighting and its visualization. The middle shows the currently pursued visualization, where the keyframes are classified binarily as good and bad. The good keyframe is highlighted in orange here. On the right, a variant with a stepwise weighting within an interval is shown, so that better keyframes are displayed with a stronger orange tone than worse ones that tend towards grey. © Authors.

Automatic georeferencing while recording

The mini-submarine Cousteau-II is equipped with a GoPro Hero 4 BE on the underside, which records videos in $1080p$ during the journey for later videogrammetric analysis. In parallel, a reduced video with a resolution of 432 × 420 pixels is delivered to the base station and serves as input for ORB-SLAM3. For the automatic georeferencing of the point cloud obtained in ORB-SLAM3, it is first necessary to select good keyframes the GPS position of which can be easily determined by the relative position to the buoy (Block et al., 2019).

Determining position and orientation relative to the buoy

The UUV based on the BlueRov2 has a relative position system and thus allows the collection of data on acceleration forces for the pitch, roll and yaw axes (see Fig. 2, right). The information obtained about the orientation of the UUV together with its speed is used in a model (see Fig. 3, left above) to determine the position of the mini-submarine relative to the known position of the buoy on the water surface. If the UUV is travelling at a dive depth d and a cable length of c with the attached buoy (see Fig. 1, right), we define a favourable time when the system has moved constantly in one direction for the time t_c. The time can be estimated with:

$$t_c = 2 \cdot \frac{\|\overrightarrow{v_t}\|}{\sqrt{c^2 - d_t^2}}$$

Currently, there is a horizontal distance c_t on the water surface between mini-submarine and buoy of:

$$c_t = \sqrt{c^2 - d_t^2}$$

With this distance c_t, the known position of the buoy $\overrightarrow{p_t}$ and the current speed of the mini-submarine (with buoy) $\overrightarrow{v_t}$ the position of the UUV can then be determined as follows:

$$\overrightarrow{p_t'} = \overrightarrow{p_t} + norm(\overrightarrow{v_t}\,) \cdot c_t$$

If the prerequisites that the system has been continuously moving in one direction for a time t_c are not given for this position determination, an alternative approach based on the catenary curve/model can be considered (Forster, 2017). In this case, the cable between mini-submarine and buoy describes a sagging chain (catenoid), the arc length of which can be described as follows:

$$l = \int_{x_1}^{x_2} \sqrt{1 + y'^2 dx}$$

Here x_1 and x_2 denote the x-coordinates of points P and P', respectively.

Weighting and prioritizing keyframes

The relative position determination of the mini-submarine and the resulting transformation of the map points into the UTM coordinate system depends on the conditions mentioned in the previous section. These conditions are used to weight the keyframes generated by ORB-SLAM3 to clarify which measured positions are to be preferred to obtain the most accurate reference. The weighting of the keyframes directly influences the weighting of the map points considered by the keyframes. The approach followed in this project is that every point that is considered by a keyframe to be good is also rated good (see Fig. 3, center/right).

This simplifying assumption disregards the number of camera positions from which a point is viewed, and how many of these positions are considered good. If these aspects are also included in the evaluation, it is advisable to use a finer graded evaluation within an interval of [0,1] to be able to represent this fine graduation of the weighting accordingly.

Selecting keyframes

The weighting of the keyframes takes place once during the integration of an image in ORB-SLAM3. To determine a good triangle for georeferencing, it is essential that the three selected keyframes span as large an area as possible (see Fig. 4, left).

We use the simple way to determine the area with the determinant or the sine formula in relation to a triangle $\Delta P_1 P_2 P_3$:

$$F_{\Delta P_1 P_2 P_3} = \frac{1}{2} \| (P_2 - P_1) \times (P_3 - P_1) \|$$

The keyframes that can now be considered can be found at the edge of the generated ORB-SLAM point cloud (see Fig. 4, right).

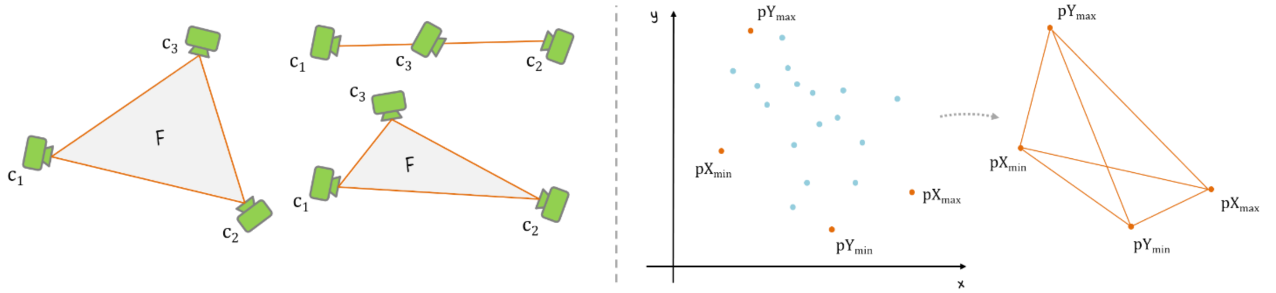


Fig. 4. Left: This figure shows the cases to be considered for the transformation of the map points. For the determination of the transformation matrix, three keyframes serve as vertices of a triangle, whereby the area of the said triangle should be as large as possible. In the worst case, the camera positions form a straight line, so that it can be assumed that the resulting transformation matrix leads to the largest distortions of map points in the UTM coordinate system. Right: The figure shows an example of the assumption used to determine the vertices for the triangle. The approach followed here is that the maxima/minima of the X/Y plane have the greatest distance to each other and thus three of the four points can span a triangle with the largest possible area. On the left side, are the relations of the points to each other, which have to be determined to define the corner points for the triangle. © Authors.

Prepare and perform georeferencing

As a starting point for the desired georeferencing, coordinates are available in two different reference systems. The camera positions generated by the ORB-SLAM algorithm at the time of acquisition and the associated tracked points are present in a three-dimensional, Cartesian coordinate system. The scaling in the monocular vision method can be defined arbitrarily at each initialization. In contrast, the positions of the buoy are given as latitude and longitude in decimal degrees in the geographic system.

To bring both into a comparable space for georeferencing, the Universal-Transverse-Mercator-Projection (UTM) (Volkmann, 2015) is used (see Fig. 5).

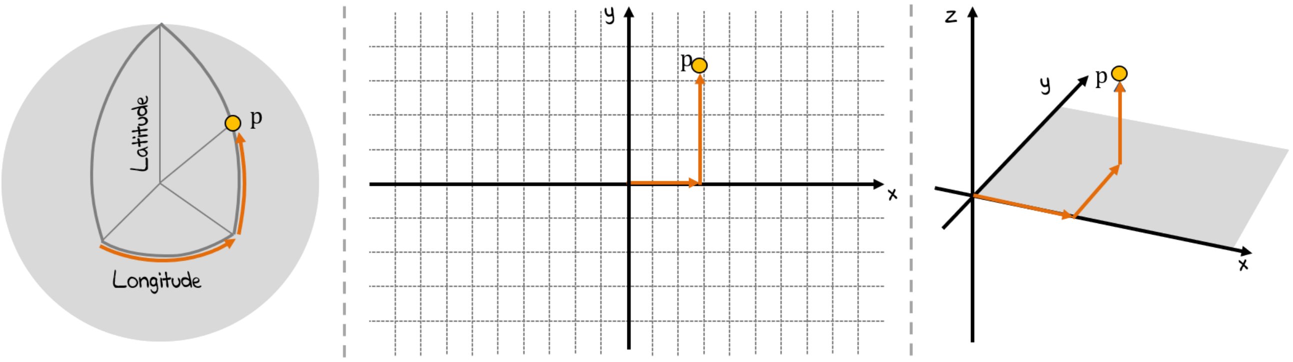
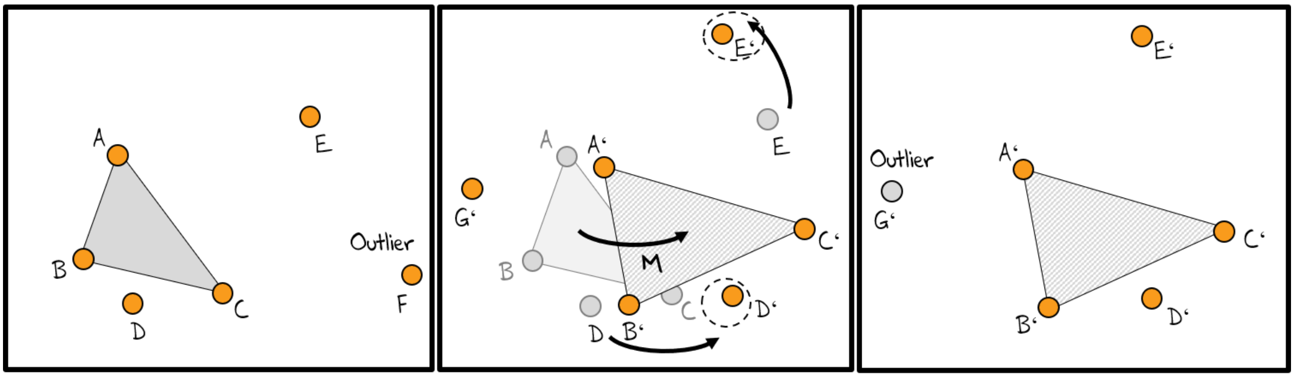


Fig. 5. Left: The geographic coordinate system, in which latitude and longitude of the position of the buoy are given. Both values are available as decimal degrees. The center of the earth or geoid, which is used for the mathematical representation of the earth, is also the coordinate origin. Center: The universal transverse Mercator projection, in which the earth is divided into individual zones. The X-axis lies on the equator and the Y-axis on the central meridian of the respective UTM zone with a false easting of 500.000 meters. The coordinates here are usually given in meters (Bill, 2016). Right: Example of a coordinate system generated by ORB-SLAM, which is the only one that automatically gives values on the Z-axis for each point compared to the other systems, in which this information has to be derived from an additional height value. Since the monocular vision method is used, the scaling of the map and thus the unit of the axes cannot be derived from the video data and must be arbitrarily defined at each initialization (Mur-Artal and Tardós, 2017). © Authors.



OrbSLAM-Pointcloud

Transformation $\Delta ABC \rightarrow \Delta A'B'C'$

GPS-Positions

Fig. 6. The figure shows an exemplary affine transformation of a triangle from one 2D space to another. On the left, we see the ORB-SLAM point cloud. Here the three good keyframe positions A, B and C are selected. On the right side, we see the corresponding GPS positions A', B' and C' of these keyframes. © Authors.

For the projection of the geographical data, it is essential to determine in advance in which UTM zone and on which hemisphere (northern or southern) the photographs will be taken, so that the correct $6°$ wide UTM zone can be selected for the projection and thus the projection distortions are as small as possible. After conversion, the coordinates of the buoy are in a Cartesian and metric representation, which simplifies the relative positioning of the mini-submarine.

A more significant challenge is the transformation of the ORB-SLAM coordinates into the UTM reference system since the exact parameters of the map generated by the algorithm are not selected until initialization. Since every keyframe stored in the map has a homogeneous pose, an affine transformation is used to determine a transformation matrix (see Fig. 6).

If the point set P, which comprises the positions of the keyframes of the previously determined triangle ΔABC, and the point set Q of the UTM positions $\Delta A'B'C'$ assigned to these keyframes are given relative to the buoy, the transformation can be determined according to the following solution using Singular Value Decomposition (Brunton and Kutz, 2019):

1. Find the centroid $\overrightarrow{c_P}$ of P and the centroid $\overrightarrow{c_Q}$ of Q.
2. Determine the optimal rotation $R = VU^T$ between the centered point sets using Singular Value Decomposition (SVD) given $[U, S, V] = SVD(H)$ and $H = (P - \overrightarrow{c_P})(Q - \overrightarrow{c_Q})^T$. The matrix H is called the covariance matrix.
3. Finally, the translation $\vec{t}$ must still be determined, with $\vec{t} = \overrightarrow{c_Q} - R \times \overrightarrow{c_P}$.

Now we can transform all ORB-Slam points $\vec{p} \in MP$ (including P) in the UTM coordinate system with $\overrightarrow{p'} = \left(R \cdot (\vec{p} - \overrightarrow{c_P})\right) + \overrightarrow{c_Q}$. The assumption is that the further away the map points are from the selected triangular area, the more their position is distorted by the transformation.

Experiments and evaluations

Several test runs were carried out in the reservoir in Oberwartha/Germany. The functionality of the newly mounted sensors with simultaneous recording should also be examined. A cable with a fixed length of $c = 1\,m$ was used between the buoy and the UUV. During the recordings, the positions of the buoy were recorded with the sensor U-blox NEO-6M GPS. This allows the position of the boat to be easily determined and stored at the keyframes in ORB-SLAM.

Out of a concrete sequence of 3,600 frames in the video, 445 keyframes with corresponding GPS positions were identified. The point cloud MP in ORB-Slam contained 29,207 points. As expected, the transformed (georeferenced) set of points is located correctly in the reservoir in Oberwartha (see Fig. 7).

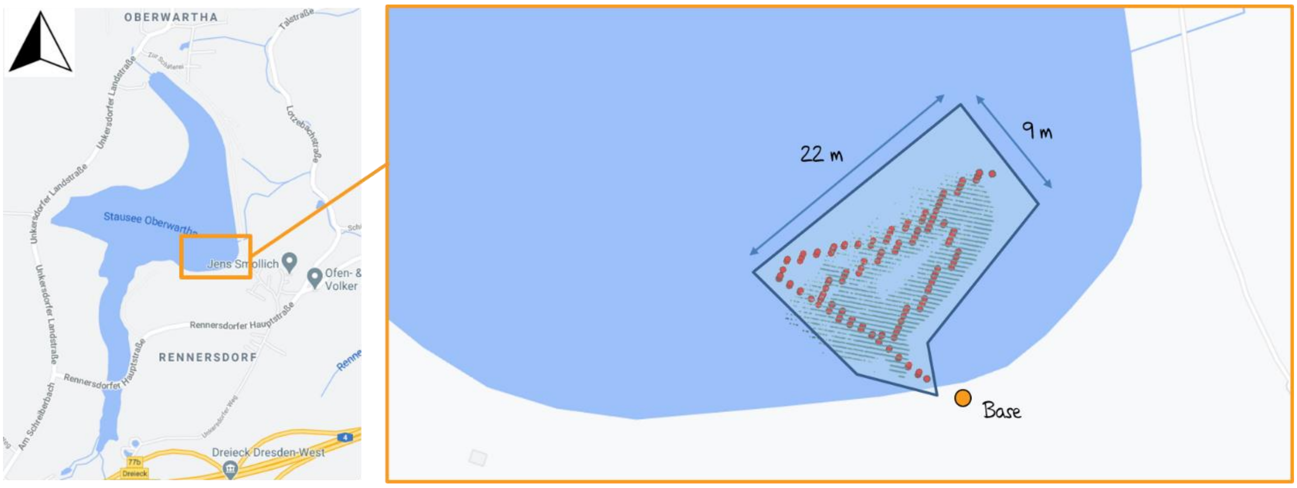


Fig. 7. Left: The reservoir in Oberwartha in Google Maps Layer with its approx. 30 ha offers a good opportunity to carry out different recording strategies. Right: A video sequence of 445 keyframes with the corresponding GPS positions (red dots) was extracted from a specific test dive. The resulting point cloud with 29,207 points (blue points) was successfully georeferenced afterwards by the presented method. © information Authors, Maps Layer from Google Maps.

5. Conclusion and future work

In this article, a robust method for automatic georeferencing of underwater point clouds is presented, which indirectly transfers the GPS information of the buoy on the surface into underwater coordinates. Currently, georeferencing is implemented as a final step of ORB-SLAM3 but shall be applied step by step during the real-time 3D reconstruction to visualize the resulting point cloud and the current or already sailed positions of the submarine on a map.

Funding

The initial project was funded by the Sächsisches Staatsministerium für Wissenschaft, Kultur und Tourismus and is now continued within a PhD-Scholarship of the European Social Fond in Germany.

Conflict of Interests Disclosure

The authors declared no conflict of interest.

Author Contributions

Conceptualization, Formal Analysis, Investigation, Methodology, Software, Visualization, Writing – original draft, Writing – review & editing: Bommhardt-Richter M., Block-Berlitz M., Brüll V.
Data curation: Bommhardt-Richter M., Brüll V.
Funding acquisition: Bommhardt-Richter M., Block-Berlitz M.
Project Administration: Block-Berlitz M.
Supervision: Block-Berlitz M.
Validation: Bommhardt-Richter M., Brüll V.

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High-Speed 3D-Documentation of Schönbrunn Palace

Pushing technological boarders in completeness, resolution, and accuracy

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Abstract: Detailed, complete and accurate 3D-documentation is of major importance for adequate management of cultural heritage sites. Respective models can be used for many applications such as mapping, status documentation before and after restoration or to generate digital twins based on Building Information Modelling (BIM) technology. A variety of sensors and techniques emerged in the past two decades, ranging from automated, low budget, out-of-the-box solutions using photos from mobiles phones up to cutting edge technologies enabling survey-grade results at millimetre scale and accuracy for entire buildings or sites. In this paper, an approach based on fast and efficient terrestrial laser scanning (TLS) for façade documentation is presented. High-up areas and the roof landscape are captured using a UAV-driven medium-format camera. By means of this technology, the entire main building of *Schönbrunn Palace* (~180 × 60m) may be documented within one working day. Sensor technology (TLS: *RIEGL* VZ400i, UAV-camera: *Phase One* iXM-100) and data acquisition strategies as well as a quick and efficient visualization approach are described. In addition, different methods for thinning point-clouds are presented and evaluated. The latter are well suited for high-detailed triangle-mesh generation. Finally, the potential of the LiDAR-sensors integrated into the latest generation of Apple's iPhone is evaluated for complementary 3D-data acquisition and modelling.

Keywords: *Terrestrial Laserscanning—UAV—High-Resolution Camera—Automation—3D Mesh*

CHNT Reference: Dorninger, P. and Studnicka, N. (2022). 'High-Speed 3D-Documentation of Schönbrunn Palace', in Börner, W., Rohland, H., Kral-Börner, C. and Karner, L. (eds.) *Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020.* Heidelberg: Propylaeum.
doi:10.11588/propylaeum.1045.c14493

Introduction

Schönbrunn Palace was the main summer residence of the Austrian emperor and is located in Vienna, Austria. Since 1996, it is listed as *UNESCO World Heritage Site* and, in addition, being one of the most important and most visited touristic hot-spots of Vienna, special requirements on continuous monitoring and documentation are given. Especially ongoing restoration and construction work require detailed, complete and accurate 3D-documentation.

Since 2000, the *Schloß Schönbrunn Kultur- und Betriebsges. m.b.H* who is operating and managing the heritage site established a continuous procedure for 3D-documentation of all objects being restored. Terrestrial (TLS) and airborne laserscanning (ALS) as well as image based structure from motion (SFM) is commonly used to document the status before the restoration as foundation for decision making, and the status after the restoration for long-time monitoring as well as for the case that something is destroyed by an unforeseen event (e.g., Dorninger et al., 2013).

In this contribution, a highly automated approach is described, based on cutting edge technology to enable the 3D-documentation including high-resolution image acquisition of the exterior of the main building of *Schönbrunn Palace* (size: ~180 × 60 m / 6,800 m²; façade length: ~550 m) within one day. Modelling, visualization and analysis of objects in the fields of cultural heritage and infrastructure monitoring will be discussed. Special focus is drawn on hybrid acquisition techniques based on TLS providing a highly accurate reference and integrating high-accuracy, high-resolution image data from a UAV-driven *Phase One* iXM-100 camera to capture high-up areas and the entire roof-landscape of the building. The presented 3D-modelling approach is based on sophisticated 3D-meshing techniques. The highly automated workflow provides models perfectly suitable for Building Information Modelling (BIM) in both, accuracy and resolution. Finally, the potential of the LiDAR sensors integrated into the latest generation of *Apple*'s iPhones is evaluated for complementary data acquisition.

Related Work

Image based solutions for 3D-reconstruction have become very popular and hence the application of respective software tools is a widespread technology. Remondino et al. (2017) compare three commonly used image processing tools (*Agisoft Metashape*, *Pix4D*, *Capture Reality*) with respect to the achievable accuracy of all necessary processing steps including bundle adjustment (BA) and SfM and they define several measures to evaluate accuracy and reliability of such methods. Especially for UAV-based applications, so called videogrammetry approaches are emerging. To simplify the data-acquisition process (i.e. selecting the view-points), entire video streams are captured and subsequently, the individual frames are processed automatically to generate 3D-point clouds. Torresani & Remondino (2019) analyse the differences between videogrammetry and "conventional" photogrammetric approaches and they describe different methods to process the frames in order to increase the achievable quality of the resulting models. They conclude their work with "*3D documentation of heritage scenarios with high-end high-resolution cameras will be never surpass*"; especially if high-resolution, high-quality, and high accuracy are of major demand. Hence, for small to medium sized objects (e.g., sculptures, fountains, ...) or for parts of buildings (some 100 m of facades, distinct parts of a roof, …) or if the visual aspect is of major interest, such approaches may be the best solution considering effort (time and financial) and achievable result. However, if aiming at high-resolution and especially high accuracy, the approach proposed in the following will be superior. Incredible progress in sensor technology development enables the acquisition of some 400 scans per day by a single operator including on-site registration of the collected data. The *RIEGL* VZ-400i laser scanner measures with millimetre resolution and precision and integrates GNSS and IMU sensors and a powerful processor for this task. Multi Station Adjustment, a fine-registration post-processing step, copes with reference points to increase the absolute accuracy and to enable georeferencing of a project (Ullrich, 2017).

Data Acquisition and Processing

The data acquisition is based on the following three steps:

1. Geodetic network measurement providing precise positions of 14 retroreflecting marker points defining a local reference frame in relation to the Austrian reference frame.
2. Terrestrial Laser Scanning (TLS) using a high-speed and high-resolution *RIEGL VZ-400i* for capturing the facades in 3D and colour.

3. UAV-based image acquisition using a high-resolution *Phase One iXM-100* medium format camera for capturing high-up areas and the roof-landscape in 3D and colour.

For this project, the work was carried out on 3 days in March (UAV-based image acquisition) and April 2020 (TLS). The entire TLS data acquisition was carried out by a single operator within 6.5 hours. For the UAV operation, it is advisable to have two persons, one controlling the UAV and one checking the camera settings and viewing positions. The geodetic network can be realized by one operator, however, two are advisable for efficiency reasons (i.e. switching totalstation and mirrors between the tripods). Therefore, considering a team of 4–5 people, the complete data capturing would be possible within one working day as the different processes do not handicap each other. With a smaller team (e.g., 2 persons), two days are realistic. Figure 1 shows the TLS with camera (Nikon D-850) and GNSS, and the UAV equipped with the *Phase One iXM-100* camera.

a *b*

Fig. 1. a) TLS RIEGL VZ-400i placed on the main staircase of the northern courtyard of Schönbrunn palace. The TLS and the on-top mounted camera have been used to capture a high resolution, colour coded point-cloud of the facades; b) DJI Matrice 600 pro with Phase One iXM-100 medium format camera as used for capturing high-resolution stereo-photos of the roof area. © Authors.

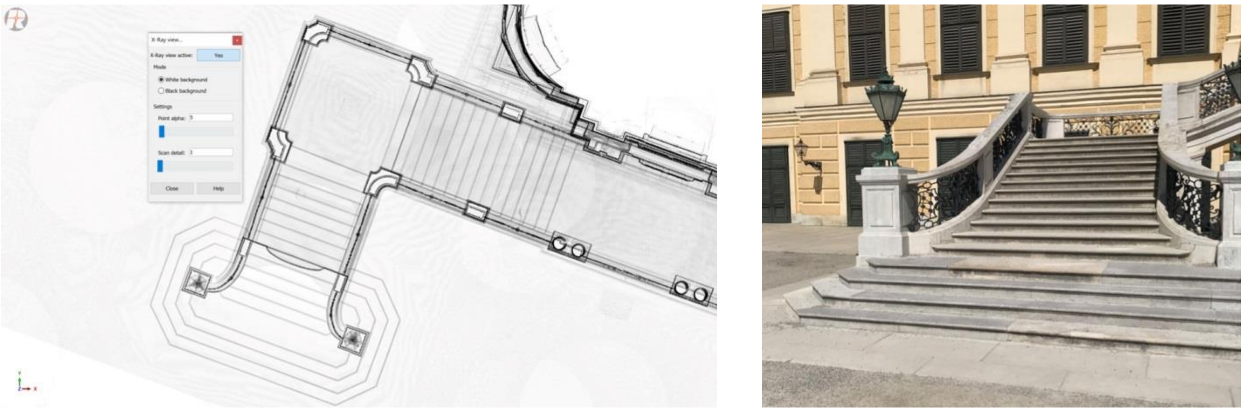
Terrestrial Laserscanning

The typical workflow of the eye-safe *RIEGL* VZ-400i laser scanner used here is to acquire one so-called panoramic scan after another. The scanning parameters have been selected to maximize the recording efficiency. A so-called “Panorama40” scan (360° × 100° field of view, 40 milli-degrees resolution) requires 45 seconds scanning time. An average of 22.5 million point measurements per scan is performed. The spatial resolution of the measuring points at a distance of 10 meters is 7 mm. Five 45-megapixel photos are taken per scan. The time required for the 292 scanning positions was 6.5 hours for a single operator. Table 1 lists the specification of the scanner.

Table 1. Technical specification of the TLS and camera sensor configuration used for the façade modelling.

Laser scanner	*RIEGL* VZ-400i
Field of view of the laser scanner	100° vertical x 360° horizontal
Angular resolution	0.040° (7 mm @ 10 m distance)
Precision of range measurement	3 mm
Attached photo camera	Nikon D-850 (14 mm lens), 45 MPix / image

Already within the laser scanner it is possible to combine the scan data of one scan after the other, thus to “register” the scan positions. This process is multi-stage, using a built-in GNSS receiver, built-in IMU (inertial measurement unit), and the subsequent *Fourier Transformation* and *ICP* (iterative closest point) algorithms (Ullrich, 2017). The post-processing of the scan data includes filtering the scans (e.g., eliminating so-called “ghost-points”), the fine block adjustment of all scan positions (“Multistation Adjustment”) by the use of the geo-referenced markers, colorize the scans from the photos and homogenization of the data (using Octree Extractor). A detail of the merged scandata of the southern staircase is shown in Figure 2.



a *b*

Fig. 2. a) X-Ray view of the TLS point-cloud highlighting vertical structures of a part of the southern staircase of Schönbrunn palace b) photograph of the same area of the staircase. © Authors.

UAV-based High-Resolution Camera

A variety of UAV-based data acquisition systems do exist ranging from “low-budget” systems using consumer camera-drones (e.g., Sun and Zhang, 2019) to heavy payload drones with calibrated, high-resolution cameras and direct georeferencing sensors. The specification of the *Phase One iXM-100* medium format camera used in this project is given in table 2.

Table 2. Technical specification of the Phase One medium format camera used on a UAV to capture the roof structure and texture.

Camera	Phase One iXM-100
Lens	RSM 35mm f/5.6 (63 × 49,4° opening angle)
Image resolution	100 MPix (11,664 × 8,750 Pixel)
Effective sensor size	43.9 × 32.9 mm

This high-end camera is superior to many competitors in several characteristics. The large sensor enables very high radiometric depths. The optimized RSM lenses reduce the number of optical elements to a minimum increasing the amount of light passing through as well as the effective resolution having positive effect on minimizing so called lens errors such as distortion or vignetting. At a mean flight height of 35 m above the roof landscape, an image resolution of 3.7 mm per pixel could be achieved. The entire roof was captured with a vertical camera position using waypoint flight. In addition, 45° tilted viewing direction towards the façade was used to complete the area along the balustrade. Due to the lighting conditions, it was necessary to plan the flights w.r.t. the position of the sun to prevent hard shadows. Figure 3 shows the potential of the sensor. The low sun elevation in March causes very dark areas at roofs facing towards southern direction while some parts of the image are still very high-lighted (e.g., sculptures). Left, an original image is shown while the centre image shows a post processed version where dark areas have been automatically highlighted while also increasing the colour depth in highlighted areas.

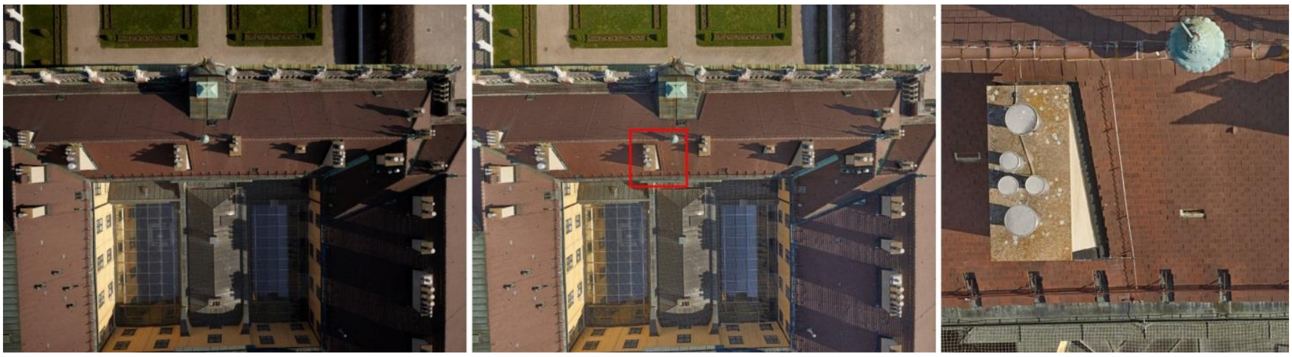


Fig. 3. Original 100 MPix image with dark, shadowed areas (left); post-processed version after applying radiometric correction and high-dynamic-range improvement (center); the bounding box of the detail (right) is highlighted as red rectangle in the center image. © Authors.

Georeferencing

Point-cloud based approaches as well as surface modelling (i.e. triangulation meshes) have been evaluated for representation, documentation and analysis of the data. As described, the TLS data has been referenced using a survey-grade network of marker-points. To reduce the amount of data, a homogeneously distributed point cloud with 10 mm resolution has been derived using a voxel based averaging approach. The UAV-image data has been processed using bundle-block adjustment and structure from motion (*Agisoft Metashape*). The resulting point-cloud has been fine referenced w.r.t. the TLS voxel-point cloud. For first visualization models, the coloured voxel-point-cloud of the façade area has been merged with a textured high-resolution mesh of the high-up areas and the roof landscape. To derive the mesh from the SfM-point cloud, an advanced implementation of the Poisson triangulation has been used as described by Nothegger (2011). Figure 4 shows the result of this visualization approach.

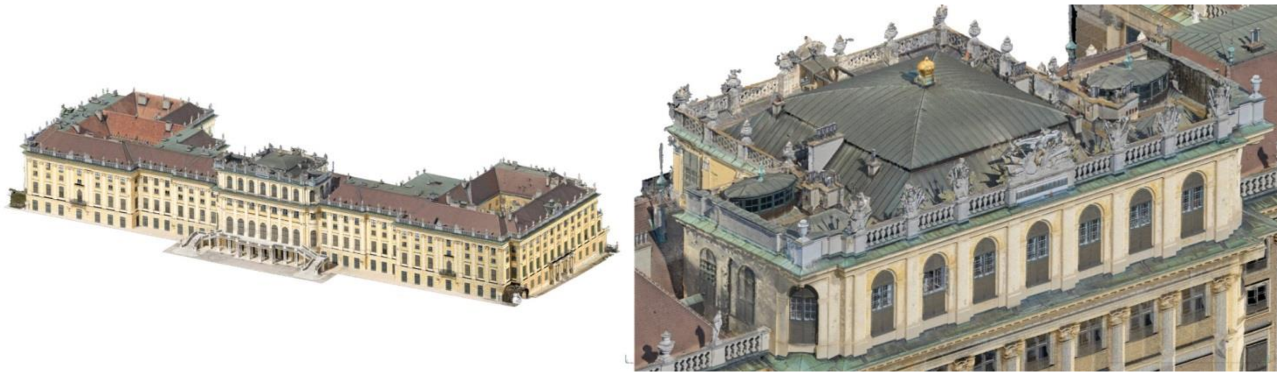


Fig. 4. Textured 3D-model of Schönbrunn Palace combining the TLS point-cloud at the façade area and a textured 3D-triangulation model of the roof structure. © Authors.

The following Table 3 summarizes the achieved accuracy of the georeferencing approach.

Table 3. Accuracy of co-georeferencing TLS and UAV data in comparison to a survey-grade control-point network.

Processing step	Accuracy
Multistation adjustment of 292 scanning positions using real-time GNSS/IMU position and orientation information as input	inner accuracy: ±1 mm
14 marker-points of a geodetic network defining the reference frame	inner accuracy: ±6 mm
Bundle-block adjustment of 458 cameras and 57 ground control points measured by GNSS or totalstation	inner accuracy: ±10 mm
Fine registration of SFM-point-cloud to TLS-point-cloud using identical, planar areas (facade, ground, roof)	absolute accuracy: ±10 mm

Point-cloud vs. Triangulation-Mesh

TLS and SfM approaches basically generate 3D-point-clouds. While TLS directly measures the 3D-points at the object's surface, SfM applies the stereoscopic measurement principle to derive 3D-surface-points. Dependent on the measurement instrument, the object's surface and several further parameters (e.g., texture, material, etc.), the individual points are not measured at their exact position. These randomly distributed errors are often referred to as measurement noise. In order to minimize this effect on the one hand and to reduce the amount of data on the other hand, averaging approaches are commonly applied (e.g., voxel-based averaging as described above). For numerous applications including visualization, distance measurement or mapping, such point-clouds can be applied "as they are" (see façade representation in Figure 4). Especially for real-time representation using web-streaming technology, point-clouds are well suited (e.g., Schütz et al., 2020). However, for several applications, 3D-surface models (i.e. mesh / triangulation models) are superior. They implicitly represent the surface topology, i.e., connected components and volumes can be determined, and volume differences (e.g., change detection), as well as sections can be computed easily. Furthermore, adaptive thinning (i.e. reducing the amount of data at smooth areas) can be applied to reduce the amount of data while preserving details at highly structured areas. To support the interpretability and for photorealistic appearance, meshes enable texture mapping with high-resolution images. The achievable quality of the mesh is dependent on the point-cloud. Figure 5 shows a Poisson triangulation of the voxel-based point-cloud (upper) and after preprocessing the data using the approach described by Nothegger (2011) (lower). It can clearly be seen, that the latter approach provides a superior result on smooth surfaces while preserving details at sharp edges or small structures.

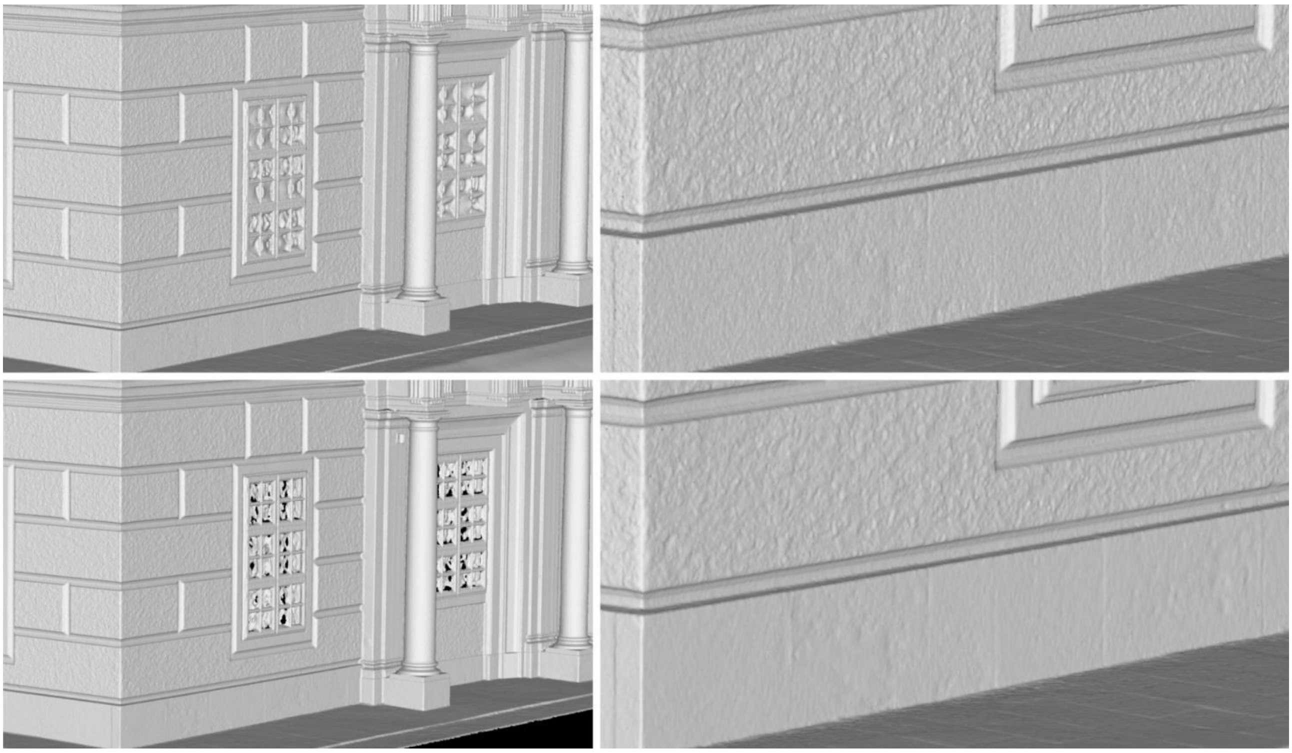


Fig. 5. Upper: Triangulation mesh of voxel-based point cloud with 1 cm resolution; Lower: Mesh derived from pre-processed point cloud. While the voxel-based approach is a simple average using a pre-defined voxel structure, the other approach applies a more sophisticated thinning and smoothing resulting in a better elimination of measurement noise while preserving structural detail. © Authors.

Fig. 6. Result of the complementary data acquisition using the iPhone-LiDAR sensor. f.l.t.r.: Original picture from iPhone; triangulation mesh from iPhone LiDAR sensor; textured 3D-mesh. © Authors.

Complementary Data Acquisition

The most recent generation of *Apple*'s iPhone is equipped with a LiDAR sensor. In combination with the high-quality camera of the mobile device, comparably high-resolution and textured 3D models can be derived automatically. For huge objects (e.g., entire buildings), the accuracy of this technology may not be sufficient. However, this kind of devices may enable in the near future for complementary data acquisition of parts of assets and an automated integration into available, highly accurate 3D-models. Evaluating the richness in detail in combination with the photo-realistic texture of the achievable models (Fig. 6), makes obvious, that, taking benefit of the automated workflow, inexperienced users might be able to generate 3D-models. By means of respective algorithms for automated registration and integration into available 3D-models (e.g., Multi-Station-Adjustment – Principal Component Analyses), this technology is very likely to integrate 3D-measurement technology into the daily work of people responsible for cultural heritage sites.

Discussion and Outlook

The described approach demonstrates that the integration of cutting-edge, high-resolution terrestrial and airborne data acquisition enables a complete documentation of huge and high objects in a very fast and hence efficient manner. The main building of *Schönbrunn Palace* can be captured in 3D within 1 day at a resolution and absolute accuracy of 10 mm and with 3.6 mm texture. We are aware, that compared to other “low-budget” approaches, the demand for the equipment is comparably high. However, considering restricted time budget (e.g., closing areas for tourists, weather conditions, legal restrictions, …), and due to the fact that field work is typically expensive, the high costs of the equipment can be overcome quickly, especially if high accuracy is required. Due to its complete coverage, the data is well suited for automated processing based on artificial intelligence and machine learning to derive data for Building Information Modeling. In addition, different approaches for point-cloud thinning as preprocessing for subsequent mesh-triangulation have been analyzed. The example given shows, that noise reduction is possible while preserving detail if an appropriate approach is applied. Finally, a low budget solution for 3D-data acquisition and modeling, based on the most recent iPhone-LiDAR-technology was presented. By means of respective automated geo-referencing algorithms, this will enable soon to complement existing, survey-grade 3D-models by inexperienced users

Acknowledgments

The project was realized on behalf of *Schloß Schönbrunn Kultur- und BetriebsgesmbH*. This work was supported by *Phase One Industrial*. The UAV flight was realized by *Gecko4K OG*.

Conflict of Interests Disclosure

The authors declared no conflict of interests.

Author Contributions

The authors contributed equally to all works related with this paper.

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Sunken Landscape

Representations of three-dimensional landscape survey data and their influence on archaeological hypotheses

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Keywords: *Visualization of Geodata—Multibeam Echo Sounding—Hydroacoustics—3D Models—Mediation of Scientific Data*

CHNT Reference: Enderli, L. (2022). 'Sunken Landscape. Representations of three-dimensional landscape survey data and their influence on archaeological hypotheses', in Börner, W., Rohland, H., Kral-Börner, C. and Karner, L. (eds.) *Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020.* Heidelberg: Propylaeum.
doi:10.11588/propylaeum.1045.c14495

Initial situation – The „Bodensee-Stonehenge“

Located 250 meters off the Swiss shore of Lake Constance and four to five meters below the water surface resides the so-called "Bodensee-Stonehenge": a collection of approximately 170 lined-up cairns, ranging over a total distance of more than 15 kilometers. The cairns were discovered during high-precision depth surveys carried out by the Baden-Württemberg State Institute for the Environment, Measurements and Nature Conservation in 2015 (Fig. 1). After initial classification in the field of geology, archaeological diving investigations came to the conclusion that the structure must be man-made. However, as of today the specific origin and purpose of "Bodensee-Stonehenge" remains unclear.[1] According to the current, yet relatively uncertain archaeological hypothesis, the cairns were built by humans around 3500 BC in a comparatively short period of time.

Since the entire structure currently hides underneath the surface of Lake Constance (Bodensee) and due to its vast dimensions, one big challenge is the proper visualization of "Bodensee-Stonehenge", essential for allowing proper understanding and conclusions of this unique archaeological finding. Therefore, the aim of this project is to visually convey the cairns to the participating researchers as accurate as possible by investigating how the representation of three-dimensional landscape survey data can influence an archaeological hypothesis. Furthermore, we will support the archaeological knowledge gain by aiming for unconventional forms of representation of the data sets and by supporting the close interaction with scientists through an interactive homepage.

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[1] https://archaeologie.tg.ch/fundstellen/ausflugsziele/weitere-fundstellen/uttwil-steinhuegel-im-see.html/9002 (Medienmitteilung vom 27. September 2019), (Accessed: 1 June 2020).

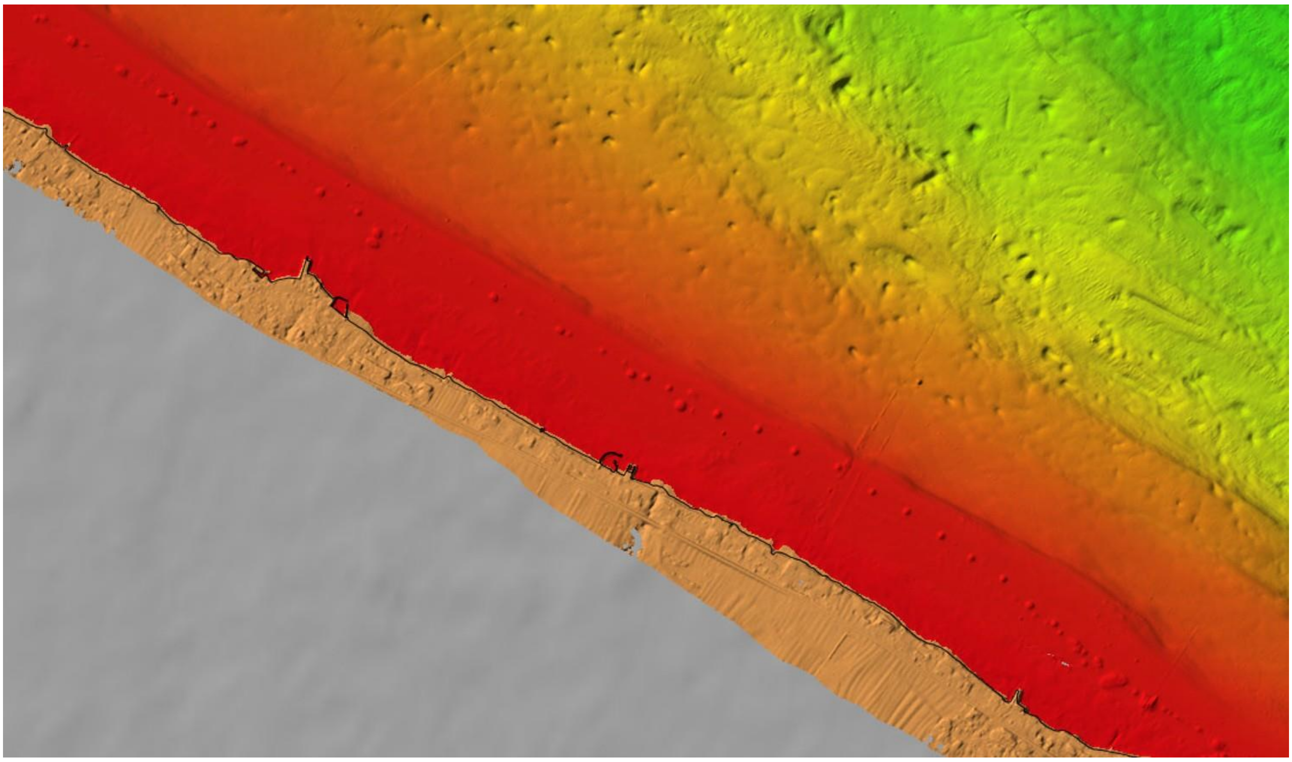


Fig. 1. Representation of a part of the cairn chain by multibeam echo sounding and sidescan-sonar by T.Wessels, Baden-Württemberg State Institute for Environment. Among other things, the color coding of the different heights, which is typical for landscape visualizations, is examined in this work and alternative ways of representation are sought in order to make the maximum information content of the data visible and present it.

Project objective and relevance

This project intends to show how scientific illustration with modern (3D) technologies can contribute to an archaeological project. Since „Bodensee-Stonehenge" remains a mystery, it is of high relevance to address how scientific images and 3D models support and influence the archeological research process and which specific creative elements promote it (Shalin, 2014) (Fig. 2).

The overall aim of this project is to unravel what effect design and representation of three-dimensional landscape survey data has on the generation of an archaeological hypothesis. Specific questions asked therein are:

Which role do design and technical design aspects play regarding the visualization of data of three-dimensional landscape surveying for the effective knowledge gain of an archaeological finding situation?

- How does three-dimensional data need to be visualized to achieve the most accurate knowledge gain? Which image components play a role?
- What role do image details, sectional views and the choice of perspective play?
- To what extent do the choice of color, creative medium and abstraction influence archaeological interpretation?

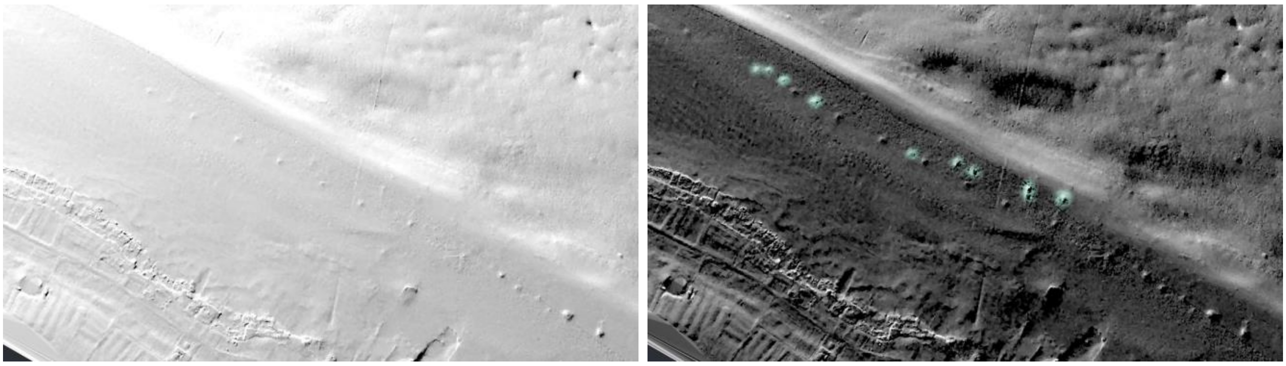
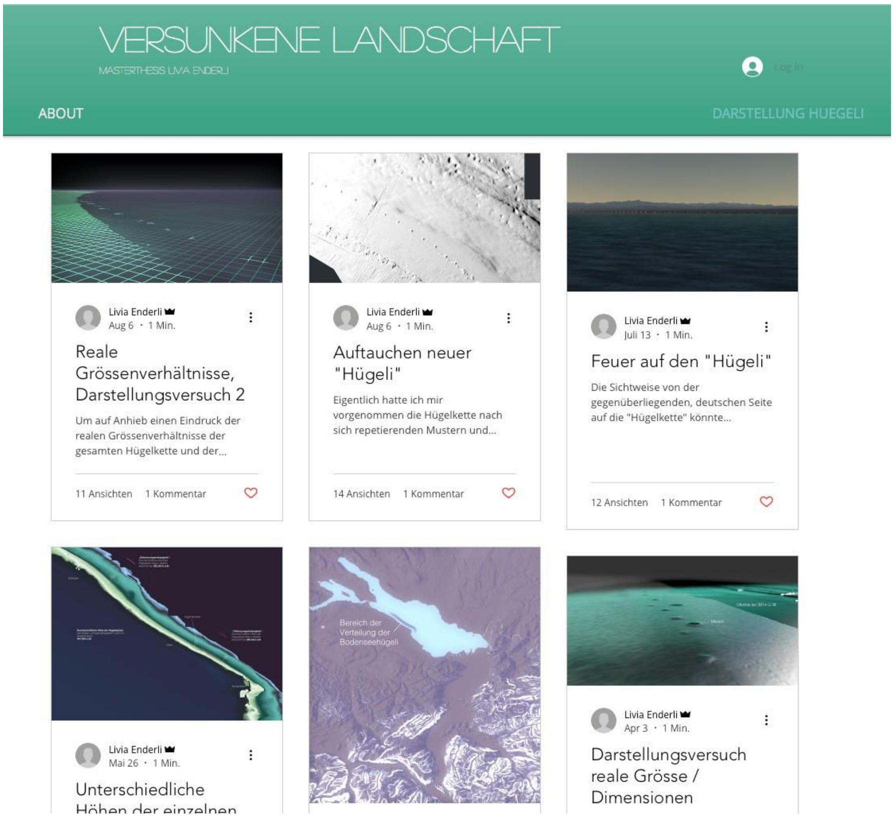


Fig. 2. Example of a first visualization experiment: The standard lighting situation of the echo sounder and sidescan sonar data in GIS makes it impossible to analyse the recorded structures precisely. Only an artificial, strong grazing light situation makes further structures and thus new, previously undiscovered cairns visible.

To answer these questions, the selected methods and image compositions will be optimized by creating variants. To find the specific design components (perspective, design means, contextualization and others) contributing to new or different archaeological findings, directly involving the archaeologist researchers is key for our project. On one hand, we will do so through direct personal contact and on the other hand, a website was created, on which archaeologists can exchange ideas with geologists and designers via blog entries directly underneath the created image proposals (https://www.sunkenlandscape.com/) (Fig. 3).



Livia Enderli
Aug 6 · 1 Min.
Reale Grössenverhältnisse, Darstellungsversuch 2
Um auf Anhieb einen Eindruck der realen Grössenverhältnisse der gesamten Hügelkette und der...
11 Ansichten 1 Kommentar

Livia Enderli
Aug 6 · 1 Min.
Auftauchen neuer "Hügeli"
Eigentlich hatte ich mir vorgenommen die Hügelkette nach sich repetierenden Mustern und...
14 Ansichten 1 Kommentar

Livia Enderli
Juli 13 · 1 Min.
Feuer auf den "Hügeli"
Die Sichtweise von der gegenüberliegenden, deutschen Seite auf die "Hügelkette" könnte...
12 Ansichten 1 Kommentar

Livia Enderli
Mai 26 · 1 Min.
Unterschiedliche Höhen der einzelnen

Livia Enderli
Apr 3 · 1 Min.
Darstellungsversuch reale Grösse / Dimensionen

Fig. 3. Insight into the communication website: The various visualization experiments are presented on the website, arranged according to the topics of the content. The archaeologists, geologists and designers involved in the project have access to the password protected website through their profile. Each contribution can be commented and, if desired, supplemented with own pictures. In this way, direct communication can take place digitally, which can be an advantage for an international team, especially in Covid times.

Choice of method and material

In a theoretical part of this project, conventions in the depiction and representation of three-dimensional landscape survey data will be analyzed (Wissen, 2009). The aim is to find which content on topography and geology should be conveyed using the respective representation conventions. What stands out are the strong exaggerations in height with which irregularities in the landscape are often depicted. In this work it is assumed that precisely these exaggerations could presumably lead to archeological misinterpretations (Fig. 4).

First, own analyses and possible hypotheses for an alternative presentation of the desired contents should be formulated. Second, in the research-oriented practical part, the conventions in the visualization of three- dimensional landscape surveying data shown by the theoretical research will be extended by own alternative ways of representation (Shalin, 2014). Specifically, we will:

- Create manageable 3D models that were surveyed during the depth measurement of "Bodensee- Stonehenge" with echo sounder and other hydroacoustics, so that the various design experiments could be carried out in computer graphics programs.
- Capture at least one hill of the cairns-chain as a precise 3D model using underwater SFM (Structure From Motion). To interpret the entire structure it is essential to study the exact morphology and the characteristics of individual cairns. In addition to a "best practice manual" for designers for the technical handling of such data sets, mainly image experiments will be created.

The three-dimensional data will be processed playfully with different design media. Analog as well as digital means can be used to study their influence on the perception and interpretation of the

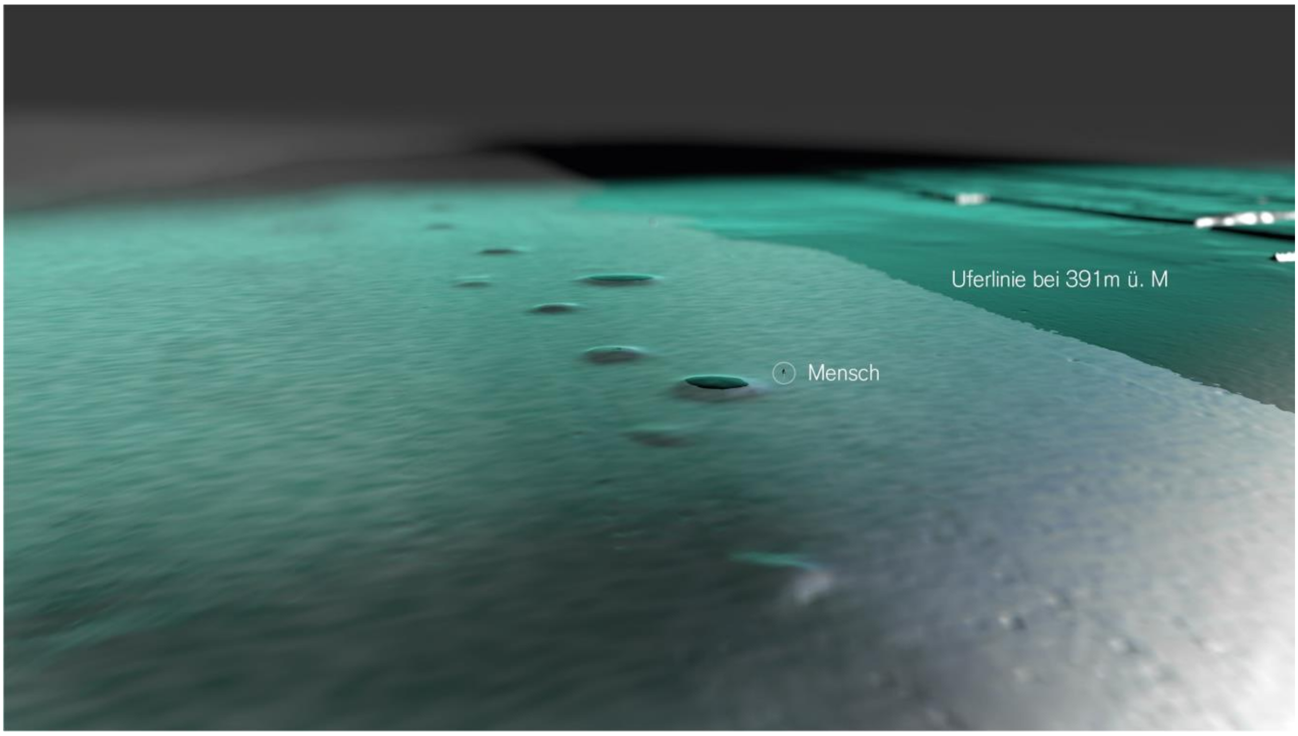


Fig. 4. First alternative visualization proposal of the multibeam and sidescan-sonar data. In this experiment, the true proportions of the cairns shall be shown. Previous visualizations of the datasets showed the cairns with a highly height exaggeration, according to the common convention of representation in the field of geology. In order to underline the real size of the cairns, a clearly defined reference object (human) was added. Attention was also paid to the choice of perspective.

archaeologists. Comparisons of classical visualizations of the datasets, which follow the usual presentation conventions in landscape depiction, and additional new presentation approaches will help finding the specific image components that can support archaeological hypothesis formation (Bardera, 2017). For a constantly improving process, the scientists are integrated into the visualization design process through conversations or the interactive homepage mentioned above.

Affiliation

The work described will be developed as part of a master's thesis at the Zurich University of the Arts in close cooperation with the Department of Archaeology of the Canton of Thurgau, Switzerland. The thesis will be evolved at the Department of Design, within Knowledge visualization. The final submission of the thesis will be in June 2021.

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Session:
Modelling the Unseen

Daniele VILLA | Lorenzo CECCON

Call

Daniele VILLA, Politecnico di Milano, Italy
Lorenzo CECCON, Politecnico di Milano, Italy

Keywords: *AI—HBIM—Remote Sensing—Diagnostics—Ontologies*

Call: AI shows great potential in helping formulate H-BIM model hypotheses of surveyed heritage sites. It can in fact link together, on the one hand, survey data from a specific site and, on the other hand, wide data-sets of other already analysed heritage sites: raw survey data and corresponding validated reconstructions as shared in common repositories. Based on such data – structured according to ontologies that embed previous research results as wrapped into the H-BIM model – AI could “make sense” of the survey data at stake and help build the relevant H-BIM model embedding such semantic taxonomy. It would then “suggest” reconstruction hypotheses, both as regards the inner structure and materiality of the surveyed sites, such as the wall material composition layers, and the historical/philological development thereof, such as the construction phases and “styles” of the site.

The session will highlight the current uses of AI for Cultural Heritage, including, but not limited to, point cloud segmentation, bimification, model-fitting techniques and fragment re-composition. It will invite scholars to devise a new paradigm in the use of AI to create historical “Digital-Twins”, to be progressively fit to the survey and historical findings over-time. The H-BIM model would then not just represent a final reconstruction result, rather help in the process of hypothesizing and testing reconstruction hypotheses, including the site diachronic development and decay history. Special attention shall be thus dedicated to the structuring of Open Data Repositories and of the sematic HBIM families contained therein, as a key “bridging” knowledgebase between survey data and H-BIM modelling, i.e. the taxonomic “glasses” through which AI would see the world. The aim is encouraging the research community to create a sound common process and knowledge build up to “fuel” and exploit AI tools.

The Visualisation of Unseen Planning States

The Planning and Building States of Early Bern Minster in Visual Comparison

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Abstract: Unseen planning states are a valuable field for the method of the “visualisation of uncertainty” as introduced by the authors in 2009, Lengyel Toulouse (2011). Here, the uncertainty is not merely the result of lost architecture, but fundamental since these planning states have never been realised. Nevertheless, it must be assumed that a clear design intention had been the basis of any begun construction. The difference to lost but originally realised buildings is therefore not relevant for the way they are represented, and all the principles that concern the visualisation of uncertainty in general are also valid here. In this respect, unseen planning states serve much more as confirmation of the relevance of this method in the scientific visualisation of non-visible architecture, and the common feature of both cases, i. e. being the result of architectural planning, reinforces the goal not to simulate built architecture, but to visualise the design on which it is based. After all, designs have always been, above all, a declaration of intent.

Keywords: *Visualisation—Hypotheses—Uncertainty—Invisibility—Contradiction*

CHNT Reference: Lengyel, D. and Toulouse, C. (2022). ‘The Visualisation of Unseen Planning States. The Planning and Building States of Early Bern Minster in Visual Comparison’, in Börner, W., Rohland, H., Kral-Börner, C. and Karner, L. (eds.) *Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020.* Heidelberg: Propylaeum. doi:10.11588/propylaeum.1045.c14497

Introduction – What are planning states

Mere planning states, as this term is used in this project, have never been realised, in contrast to building states that have been realised. Nevertheless, it must be assumed that a clear design intention had been the basis of any begun construction. As often in the scientific world of archaeology and building history, the verbal description of research results is the primary medium of communication. The set of illustrations that have been developed in this project intended to cover planned and realised building states. Thereby it is to be considered that both, not realised plans and states of the building that might have existed, are unseen and therefore hypothetical as they have never existed, even if of different degree of uncertainty. This is called “uncertain knowledge” and consequently its translation from text into image is referred to as the “visualisation of uncertainty”.

Planning phases serve as a continuation of this method, since the assertion that there are pure planning phases as opposed to realised construction phases extrapolates the degree of uncertainty into the fundamental. It is no longer only a matter of reconstructing knowledge that existed before, in the hope that someday documents or drawings might turn up documenting the lost buildings or parts of buildings whose appearance is being attempted to be reconstructed. No, mere planning phases are per se indeterminate because they have never been realised. They constitute architecture that has not passed beyond the design planning stage, except for the few but sufficiently explicit indications that lead to the assumption of their existence. As a result, the modelling of the unseen as well as the visualisations are primarily abstract, just as declared in the visualisation of uncertainty, but just alike, all available methods of traditional architectural photography have been taken care of in order to make the church still as vivid as possible.

A suitable appearance

Creating visualisations for a contribution to historical building research first of all raises the question of a suitable appearance. The Bern Cathedral (Fig. 1) is a building that is not only marked by changes in plans but also by replacements. In addition, a largely unknown predecessor building stood in about the same place.

Fig. 1. Bern Minster platform around 1529, view from the opposite bank of the Aare (© Lengyel Toulouse).

The visualisation project was realised within the framework of a multidisciplinary, four-year research project at the University of Bern and the Bern Minster Foundation with archaeologists, art historians, building researchers, the cathedral architect, and stonemasons. The visualisations published by Lengyel and Toulouse (2019) were an integrated part of the research and thus contributed to the gain in knowledge.

The changes in planning took place during the construction process. There are only a few findings from the predecessor building, and changes in the planning of the cathedral are indicated by structural elements, but without revealing all the details of the rejected plans. In many cases, therefore, there are clear indications of circumstances which cannot be definitively clarified on the basis of the present state of knowledge, as published by Druzynski v. Boetticher (2019). This is then called uncertain knowledge. For example, it is undisputed that there was a predecessor building (Fig. 2).

Fig. 2. Predecessor building from the opposite bank of the Aare, 1310–1334 (© Lengyel Toulouse).

However, the few foundation remains allow for several equally plausible building forms. The same applies to changes in planning. The indications of such changes are much more subtle than the remains of the previous foundation. They include, for example, begun vaulting beginners, whose form and orientation appear strange in the realized building, while they would fit for an alternative completion that does not correspond to the present one. The finding thus suggests a change in planning during the progress of the construction, but above all it raises the question of the form that was originally intended. A fundamental distinction is therefore made between planning and implementation stages. As in the case of the predecessor building, it is obvious that the cathedral is completed or compared with other buildings, which allows hypotheses to be made about the rejected planning.

In both cases, the predecessor building and the unrealized plans, the uncertainty is not only that many things cannot be clarified. The uncertainty also includes several mutually exclusive, i. e. contradictory possibilities. In view of these uncertainties, the fundamental question of what should and can be shown in such a visualisation is added to the considerations of an appropriate appearance. A visualisation is most likely to serve scientific knowledge if it remains as close as possible to the hypothesis. Since historical building research moves argumentatively between construction and appearance, it is obvious that the illustration should also be based on the specific characteristics of the phenomena investigated, i.e. to visualise both the constructive principle and the resulting spatial impression in a comprehensible way. To this end, some aspects are deliberately excluded from the depiction, of which perhaps the most obvious ones will be briefly explained in the following, namely materiality, stone joints and sculptures (Fig. 3).

Fig. 3. View into the choir, 1517–1528 (© Lengyel Toulouse).

The reproduction of each individual stone could only include those surfaces that are still preserved, while due to the uncertainty described above, stones that are no longer preserved as well as stones that were planned but not built upon could basically only be represented fictitiously.

The situation is quite similar with the representation of materiality. Equally the representation of the actual surface condition of each individual stone would be limited to the still preserved stones. All other surfaces would have to be shown without materiality anyway. Because a fictitious, but only apparently lifelike representation would create the wrong impression of certain knowledge. Moreover, the visual effect of natural surfaces would clearly dominate the geometric statement behind them. In order to keep the proportion of purely fictitious additions to a minimum, it was therefore decided to also exclude materiality from the present illustration of the building research hypotheses.

Finally, sculptures were excluded for various reasons. Firstly, they are of secondary importance for the building research investigations and statements. Although their volumetric presence already shapes the spatial impression, especially on the important sculptured western portal that has undergone separate research as published by Nicolai (2019), the direct comparison between construction phases with and without sculptures seemed to be dispensable to building research. On the other hand, the limitations of uncertainty are particularly applicable to the sculptures, since here too, in many phases, especially in the planning stages that were not realised, it is unclear which sculptures were erected or planned at what point in time and at what location within or on the outer facade of the cathedral.

The choir vault

An exception to this is the choir vault. The iconoclasm of 1528, which makes it difficult to locate not only the fragments recovered in the Bern sculpture find of 1986, fortunately left out the area of the choir vault. This has made it possible to visualise the individual steps of the construction technique of the vault up to the sculpturally worked keystones in an exemplary manner. Although this would also have been possible with the help of abstract placeholders, the construction method, which places the sculptural keystones on temporary wooden supports before the ribs are erected, appears all the more impressive in the contrast between the geometric form of the vault ribs and the sculptural form of the keystones. However, since this is also a schematic representation overall, and the individual sculptures are not the focus here either, only a small selection of keystones was scanned three-dimensionally. These were distributed alternately over the ribbed crosses so that the overall picture of regular vault ribs and variable keystones is preserved.

The limitation of the visualisation to space-forming surfaces and edges is also done in order to be able to compare planning and realisation statuses directly and also in an urban context. In this way, for example, the state of the cathedral during the construction of the choir walls can be directly contrasted with the then still upright remains of the predecessor building, without the differences in knowledge about both buildings impairing the overall spatial impression.

This consistency of the image, i.e. the cohesiveness of the representation, is a fundamental prerequisite for the architectural evaluation and interpretation of the hypothetical appearance of a historical condition. Closeness means that all components of the image are coordinated with each other. In addition to the restriction to space-forming surfaces and edges, this applies above all to the image detail. This is chosen in each picture in such a way that all components of the picture make a conscious statement about the depicted hypothesis (Fig. 4). Above all, however, the actual and unavoidable spatial limitation of the virtual three-dimensional model – to a certain extent the edge of the model construction table that forms the basis for the visualisations – is not recognisable in any representation.

Fig. 4. Hypothetical planning state, around 1470 (© Lengyel Toulouse).

The unseen urban context

The external appearance of the Bern Minster has been researched with sufficient certainty at all the periods depicted that a hypothetical representation is possible in an abstracted but nevertheless complete appearance. In order to give the viewer such a complete overview of the state of the hypotheses, several twin images show the cathedral from the southwest and from the northeast, thus giving the impression of walking around the church.

These representations, which focus on the actual church building, already show sections of the urban context in which the churches were located. For representations that focus on the urban context, on the other hand, a separate section of the picture was chosen and, together with it, a different direction of view, namely as a view from the southwest that reaches from the cathedral platform to the town hall in the north. The section chosen here shows the transformation of the city without revealing areas that are not intended to be commented on. In addition to the cathedral platform, the content includes the cathedral forecourt in front of the west portal, the immediate surroundings including the enclosure wall, the Deutschordenshaus, the former town hall directly east of the cathedral and the new town hall in the north at the end of Kreuzgasse. The remaining buildings of the urban environment are shown schematically. Although they are based on the actual plots – although only on the present ones, which may have been different at the times depicted – they also use a uniform appearance, with a few striking exceptions, in order to limit the image statement to the pure urban texture. Their essential features are buildings with eaves, round-arched arcades and wide roof overhangs, as well as courtyards separated by walls. This appearance, however, is also based on today's existing buildings, only the height of the buildings is in accordance with the Sickinger Plan of 1607, and here, too, the deliberate abstraction is necessary in order to do justice to the uncertainty in the knowledge and not even to address the actual appearance of the façades. The deliberately chosen schematic form of these pictorial components thus corresponds to the significance of the urban texture in the context of the focus on conveying the building research hypotheses of the Minster (Fig. 5).

Perceiving the uncertain

The most obvious feature of the visualisations of the hypothetical character of the building research findings and claims is the abstraction of the virtual model. Its complementary counterpart is the realism of the virtual projection. A visualisation does not consist of the virtual model only, allowing it to be viewed in any way. Rather, as already explained above in the section on the format of the visualisation, it is not only the viewing direction that determines reception, but the full range of photographic parameters. The challenge of a scientifically substantiated and at the same time immersive visualisation is to combine two initially opposing endeavours. The first is abstraction with the aim of modelling, as far as possible, only those object edges that are explicitly part of the building research statement and are thus evident from a building research point of view or at least well-founded. The second is the reference to classical architectural photography with the aim of immersion, i. e. to allow the viewer to imagine himself completely in the depicted world.

But why only black and white? It would easily be possible to depict polychrome architecture by juxtaposing different colour variants in the sense of the uncertainty of knowledge. But polychromy dominates a visualisation in such a distinctive way that the enormous uncertainty that arises from the fact that, although in principle polychromy is beyond question, individual specific colours and assignments on surfaces are largely unknown, obscures the underlying relatively high level of certainty in knowledge about geometry. Monochromatic representations, on the other hand, are able to focus the attention of a visualisation on the geometry and thus achieve a significantly higher degree of certainty of knowledge of the image as a whole. And it is the consistency of the black-and-white photography that excludes the illustration of individual elements such as the sky in blue or the stained glass windows of the Bern Minster in colour, for both would transform the black-and-white photo into a colour photo and suddenly turn the clearly polychrome architecture white. So, an abstention would become an obvious falsification. The abstraction of colour, the black and white photo, on the contrary, abstains from the statement on polychromy and remains true to the scientific hypothesis.

Fig. 5. The minster in its urban texture, around 1530 (© Lengyel Toulouse).

Funding

Swiss National Science Foundation SNF, Grant number 150217, Applicant Bernd Nicolai, Department of Art History, University of Bern

Conflict of Interests Disclosure

No financial or personal relationships with other individuals or organisations, such as sponsors, that could make this work appear biased or influenced.

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Data curation: Lengyel, Toulouse

Funding acquisition: Nicolai

Methodology: Lengyel, Toulouse

Resources: Baeriswyl*, Druzynski, Lengyel, Nicolai, Schweizer, Toulouse, Völkle*

Supervision: Baeriswyl, Druzynski, Lengyel, Nicolai, Schweizer, Toulouse, Völkle

Validation: Baeriswyl, Druzynski, Lengyel, Nicolai, Schweizer, Toulouse, Völkle

Visualization: Lengyel, Toulouse

Writing – original draft: Lengyel, Toulouse

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AI: Inferring Unseen Pieces to Solve the Heritage Puzzle

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Keywords: *Artificial Intelligence–HBIM–Digital Twin*

CHNT Reference: Ceccon, L. (2022). ‘AI: Inferring Unseen Pieces to Solve the Heritage Puzzle’, in Börner, W., Rohland, H., Kral-Börner, C. and Karner, L. (eds.) *Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020.* Heidelberg: Propylaeum.
doi:10.11588/propylaeum.1045.c14498

Intro

The relationship between architectures and models has always been of a dialectic duality: architects have been creating models of the geometries to be built and built geometries have been represented by means of models. Often implicit rules applied as to what made a model “resemble” or correctly capture an architecture. Frequently, the most relevant corresponding aspects were the geometrical and mathematical relationships and proportions. In some cases – as for some Gaudì creations based on reverse catenaries – models have been used to even “calculate” the geometrical structure of the prospected architecture based on physics.

A series of converging technologies now promises to make the relationship between model and architecture even more biunivocal and dynamic. In particular, a “Digital Twin” of an existing architecture or urban spaces allows for a simulation running in parallel to reality, and can be used in forecasting and detecting abnormalities, hence potential issues. The backbone of such a technology is the Building Information Modelling (BIM), a semantic-based and Object-Oriented modelling system where every “element” of reality is an “object”, classified within object families and classes. It opens up the opportunity to both hard-code and to infer the relationships among objects and their behaviours, both statically (as building elements and interfaces), and dynamically, also as regards changing datasets stemming from new research findings. Hidden, hence unseen, objects – similarly to dark matter in physics – also seem to play an important role in the overall model fitness.

Aim and methodology

Can we imagine a new paradigm in purposefully using artificial intelligence (AI) in Heritage modelling, whereby all available data contribute to create new knowledge by inferring “unseen” aspects of reality? A critical review of use cases of AI for “seeing” hidden data, and keeping the model reality-twin, is carried forward in view of being applied to two promising areas: hidden physical structures and historical layers.

Prospected advances

To start with, it is worth recalling the state-of-the-art of HBIM knowledge-base system. For instance, “The INCEPTION project has defined the approach and the methodology for semantic organization and data management toward H-BIM modelling, and the preliminary nomenclature for semantic enrichment of heritage 3D models. The organization of consolidated knowledge is performed following a specific workflow in order to get them suitable for their reuse into H-BIM semantic model, accordingly to digital documentation and capturing protocols that have been developed" (Maietti et al., 2019).

Until now, all the above has been carried forward somewhat "by hand", through the work of researchers and practitioners. Artificial Intelligence (AI) promises to help maintaining the model and the underlying available knowledge-base datasets aligned over time, also along new knowledge accrual. Trained AI algorithms can draw on huge multidimensional and growing knowledge-bases to "foresee" what – based on the usual correlations within the dataset – would seem as the most probable interrelations among architectural elements. Moreover, by comparing them with the data of reality, the model could self-adjust to fit them. Could then the model help formulating grounded hypotheses as to non-observable – hence unseen – aspects of the heritage architecture at stake? They are in fact the missing piece of a puzzle where every observable aspect is linked, physically and historically, to other observable and non-observable ones.

AI and unseen (hidden) physical structures

New pieces of research have shown the potential of AI in reconstructing physical shape of not directly observable geometries. The question is whether and how such technology may help creating a HBIM model with less human intervention and less degree of uncertainty. In fact, while HBIM models can't be limited solely to the representation of the observable parts of an architecture – the Object Oriented logic requires every element to be a complete closed geometry with attributes – usually HBIM models must rely on the mere skills and experience of the modeller in order to hypothesize (smart guess) those hidden parts and phenomena which need to be included in the model. New approaches have been now successfully tested. For instance, "a Multimodel-based approach has been developed in which stone facades of existing buildings are digitized as IFC-model by using proxy entities and linked with web ontologies for semantic enrichment. Additionally, detected anomalies in the stone structure are implemented and linked with geometrical representations. By utilizing additional rules and inference mechanisms, the anomalies can be classified, and a knowledge-based damage assessment is processed" (Seeaed and Hamdan, 2019). The logic of such projects could be stretched to help enriching the knowledge-base of a HBIM model, based on which AI can help formulating and checking the correlation between the available (observable) data and the model, based on what is usually found in analogous situations. Moreover, once modelled, a reversed use of AI, specifically of Generative Adversarial Networks (GANs), can be used to maintain the model/twin aligned with the changing available data.

AI and unseen historical layers

There is a more futuristic field in which it seems AI can play a major role for the creation of a model encompassing unseen features. It is the case of historical layers. In fact, provided that such layers have left traces within the used knowledge-base, and that usually "similar" formal architectural phenomena tend to be repeatedly expressed within a certain time and space, it is possible to imagine

Fig. 1. A series of images created by Ethan Hein using AI GANs technology (https://www.flickr.com/photos/ethan-hein/with/26983399703/)

how AI could help drawing grounded hypotheses as to the past historical conformation of the architectures at stake. A semantically and historically well-organized knowledge-base is of course a prerequisite, but such an approach – especially when multiple data sets and models stemming from sound research are put together – could even help modelling the present as the result of a dynamic succession of different phases.

It is worth here quoting a ground-breaking piece of research whereby AI helps “translating” spatial relationships into different architectural “styles”: “…studying the driving forces of the composition is maybe where AI can offer us some meaningful answers […] At a more fundamental level, we can think of styles as being the by-product of architectural history. If there is within each style a deeper set of functional rules, then studying architectural history could potentially be about understanding the evolution over time of these implicit rules. Being able to encapsulate each style could allow us to go beyond the study of precedents, and complement it by unpacking the behavior of GAN-models such as the ones trained here. Their ability to emulate some of the unspoken rules of architecture could allow us to address the ‘quality with no name’ embedded in buildings that Christopher Alexander defines in his book The Timeless Way of Building. AI is simply a new way to study it” (Chaillou, 2019). Then, somehow reversing such dialectic between knowledge-base and model, a new framework is proposed by which GANs-based AI techniques, instead of generating architectures in a certain historical “style”, are used for devising plausible historical layers based on what survives of each “style” in the heritage building at stake.

Discussion

For the shown “reverse” use of AI (GANs) in seeing hidden Heritage layers to really bring disruptive capabilities to the field of HBIM modelling and digital twin, more experimentation seems needed for widening the current state-of-the-art use cases. In particular, wide and solid knowledge-bases – whereby it is possible to draw on shared and semantically “normalized” research contributions from various teams over time – appear as being the fundamental prerequisite for all this to happen, and probably will constitute the real challenge.

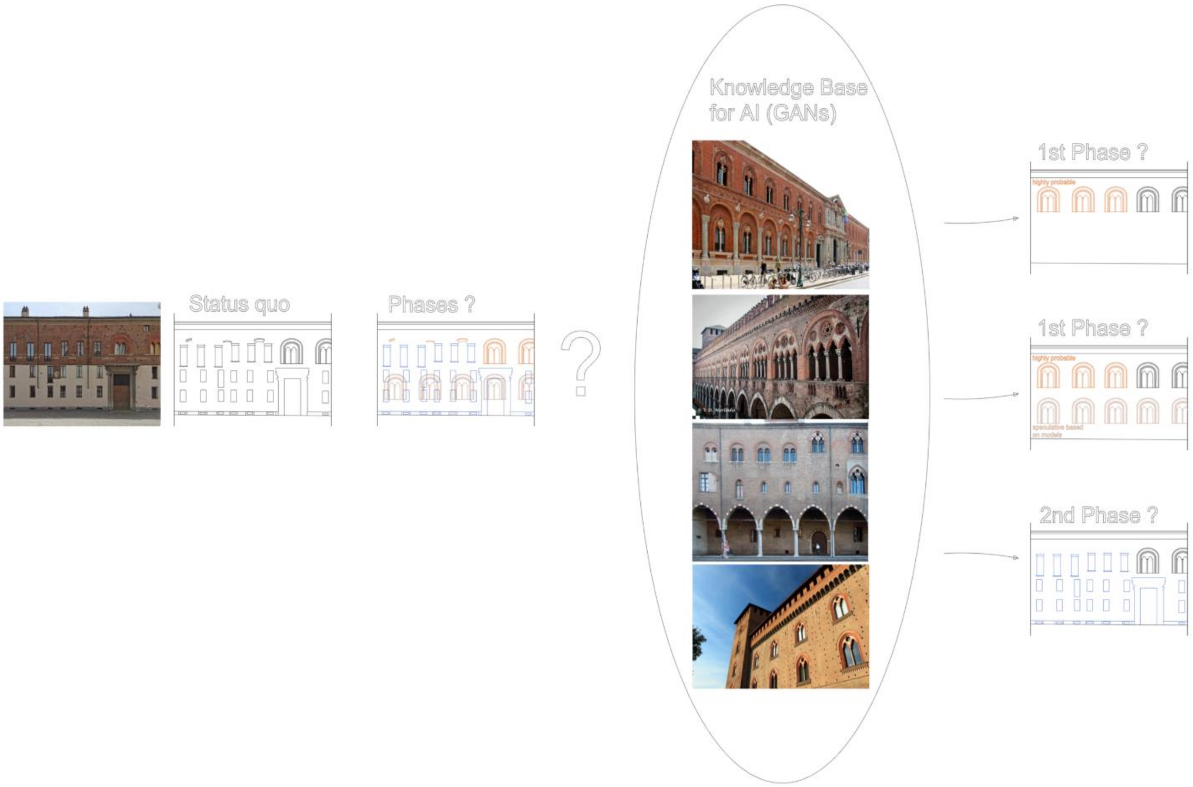

Fig. 2. "Seeing" the historic layers in the Palazzo Arcivescovile in Milan through a proposed reverse GANs generation process. (Image [1] and graphics by the Author. Images 2,3,4,5 respectively by: [1] Sailko; [2] Vittorio Destro;[3] Massimo Telò; [4] Matteo Ruaro)

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Session:
PhD/Master session 2020

Martina POLIG

Call

Martina POLIG, Science and Technology in Archaeology Research Center (STARC), Cyprus

Keywords: *Student—PhD/Master—Best Student Paper—Free Admission*

A crucial aspect of CHNT is that it brings together researchers from different fields and backgrounds, creating a platform that enables and promotes the exchange of ideas. This discussion can only benefit from the input and perspectives of the young scientific generation. Their participation enriches the scientific ambient with their fresh views and gives them the opportunity to confront themselves with their peers in the context of an international conference. Therefore, we invite 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 are especially welcome.

The topic of the presentation should be within the scope of cultural heritage and new technologies. However, presentations that are within this year's main topic "Artificial Intelligence – New pathways towards Cultural Heritage" will be given preference. The session wants to encourage young scientists to present for their first time at an international conference.

To facilitate and encourage the participation the conference organizers agreed that every presenter will get free admission to the conference. Furthermore, accepted speakers will be considered for the Best Student Paper award of CHNT and have the possibility to win the price of publishing their paper in the journal "Open Archaeology".

The Award "Best Student Paper" was awarded to Kristina Gessel, Stephen Parsons, Clifford Parker, William Seales with their paper 'Towards Automating Volumetric Segmentation for Virtual Unwrapping'. It will be published in the journal "Open Archaeology" shortly after the CHNT proceedings.

AI Guided Panoramic Image Reconstruction

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Abstract: Due to the development of virtual reality, virtual tours have become commonplace. Panoramic image is the core to generate such immersive environments. However, the moving foreground will degrade the visual quality and cause ghosting artifacts on the panorama, making difficult the representations of most popular crowned city places as the Grand Place of Brussels where there are always people all the day. This paper addresses this problem by a novel panoramic image reconstruction pipeline, adding a moving foreground objects removal step, before a state-of-the-art stitching phase, to both guide the pictures acquisition and obtain a clean panorama. The proposed solution consists of analyzing the pictures in parallel with their acquisition to know whether they should be taken again, considering that it is difficult to obtain an image without any moving object and that each new contribution makes it possible to obtain new small background areas. Several model-based and artificial intelligence-based foreground removal approaches are proposed and evaluated. Best results are obtained by using an object detection convolutional neural network, Mask R-CNN (He et al., 2017), to detect foreground objects and using mixture of gaussians background subtractor, MOG2 (Zivkovic, 2004), to detect shadow. The pure background is extracted from a series of images according to the foreground detection masks. Experimental results show that our panorama generation pipeline effectively removes the moving objects.

Keywords: *Moving Object Detection—Moving Object Removal—Panoramic Imaging—Image Stitching*

CHNT Reference: Schenkel, A., Zhang, Z., and Debeir, O. (2022). ‘AI Guided Panoramic Image Reconstruction’, in Börner, W., Rohland, H., Kral-Börner, C. and Karner, L. (eds.) *Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020*. Heidelberg: Propylaeum.
doi:10.11588/propylaeum.1045.c14500

Introduction

The panoramic image gives an extensive angle of view, which is widely used in immersive environment generation and virtual reality. Used to create virtual tours of museums, art events, or world heritage sites, 360 panoramic view must take care of human presence during the acquisition to avoid any disturbance in the final product.

The construction of the panoramic image is accomplished by stitching multiple photos. However, when the photos are captured in a high-traffic place, the moving objects will degrade the visual quality and cause ghosting artifacts on the panorama because of the moving foreground objects in the seam of two images. Furthermore, the pure-background panorama without the interference of foreground objects is preferred when the scene is displayed. This project aims to solve the acquisition and the moving foreground interference problem in crowded places where it is never possible to have such a museum of world heritage without visitor, like popular city places such as the Grand

Place of Brussels where there are always people, even late at night, and generate a high-quality panorama of pure background visitors (Fig. 1).

Our solution consists of adding a moving foreground objects removal step, before a state-of-the-art stitching phase, to both guide the pictures acquisition and obtain a clean panorama, preferably without moving objects, but with coherent objects if is not possible due to some acquisition limitations. Several model-based and artificial intelligence-based approaches are proposed and evaluated. Best results are obtained combining both approaches: Mask R-CNN for object detection and MOG2 for shadow detection. Result therefore currently depends on the acquisition time and shots to remove visitors.

Fig. 1. Grand Place in Brussels, based on limited time acquisitions. Objects and visitors, stationary during all the acquisitions, could not be correctly removed (© Arnaud Schenkel).

Panoramic Photography

Since always, crowned and fortunate people liked paintings in general or panoramic view, carried out on walls, tapestries or panels, showing wars or hunting scenes. Its emergence among a wider audience dates more from the 18–19th century. The panoramic views then allow the public to be immersed in new surroundings, such as simple landscapes, but also topographical views and historical events, with paintings such as the Panorama of London from Albion Mills (1792), the Cyclorama of Jerusalem (1895), the Panorama of the Battle of Waterloo (1912), and the Pantheon of the World War (1914), or with pieces of art, like the Eidophusikon (1781, Philip de Loutherbourg), and the Diorama Theatre (1821, Louis-Jacques Daguerre and Charles Marie Bouton). Table 1 gives a summary of the characteristics of four well-known panoramic paintings.

Table 1. Characteristics of four well-known panoramic paintings.

Date	Name	Artist(s)	Dimensions
1792	London from the Roof of Albion Mills	Robert Barker	43 cm by 330 cm
1895	Cyclorama of Jerusalem	Paul Philippoteaux (based on Bruno Piglhein's work	14 m high / 110 m in circumference
1912	Panorama of the Battle of Waterloo	Louis Dumoulin	12 m high / 110 m in circumference
1914	Pantheon of the World War	Pierre Carrier-Belleuse and Auguste Gorguet	14 m high / 123 m in circumference

The birth of photography did not profoundly change the style of panoramas, as they often remained a succession of images rather than a continuous image. From the beginning of the 19th century, specialized panoramic camera designs were being patented and manufactured for making panoramas. Several approaches are thus developed:

- using a specialized rotating lens camera and a curved filming plate: Joseph Puchberger invented the first-hand crank driven swing lens panoramic camera in 1843 but limited to record a 150-degree field of view instead of a full 360-degree view. In 1845, Frédéric Martens take panoramic shots of Paris using a chamber with a hundred fifty degrees opening;
- using a specialized camera with a wide field of view, up to 180°: Kodak proposed his first panoramic camera, the No. 4 Panoram, in 1899, to obtain quite similar result but with an easier solution;
- taking a series of images which were then shown placed next to each other to create one image.

Among the oldest and most famous panoramic pictures, Martin Behrman's eleven-panel panorama shows the state of San Francisco from Rincon Hill in 1851. Bernard Otto Holtermann and Charles Bayliss capture Sydney Harbor from Lavender Bay to produce one of the most impressive photographic achievements in 1875, composed of twenty-three albumen silver photographs (178 centimeters). Another example is the panorama of Verdun, filmed from the Fort de la Chaume in 1917.

Since the invention of digital photography, it is easier and much less expensive. But modern solutions are based on the same ideas. Fig. 2 gives a summary of the acquisition solutions to produce panoramic images.

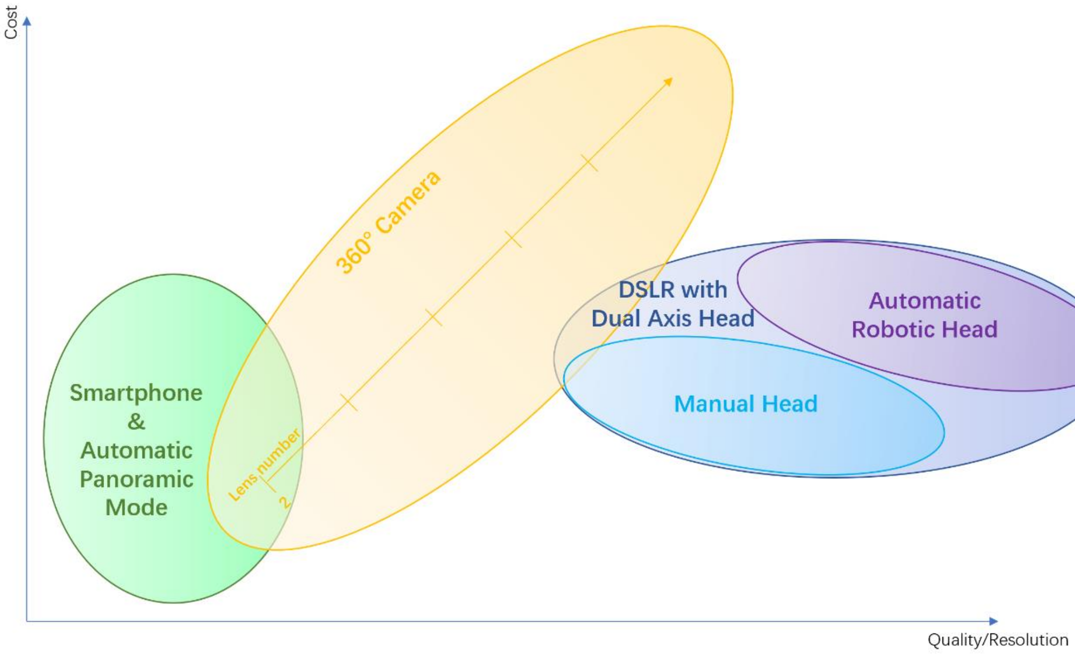


Fig. 2. Inventory of acquisition solutions for producing panoramic images (© Arnaud Schenkel).

Software solutions embedded in modern cameras or smartphones allow panoramic photographs to be taken simply by rotating the device. The result obtained is often limited in terms of resolutions and makes it difficult to deal with the presence of obstacles in the scene.

The 360° cameras have the main advantage of capturing the whole space at one time. However affordable 360° cameras are limited to two wide angle cameras, producing images of limited quality in terms of distortion and resolution; while devices composed of a larger number of cameras allow higher quality, also at a higher cost.

The current most common method for producing high details panoramas is to take a series of pictures by turning the camera between each shot, considering an overlap between two consecutive shots, covering the full spherical environment and stitch them together. Two solutions for that: manual acquisition or using automatic robotic head. The number and the angular positions of shots thus depend on the characteristics of the camera (sensor size, orientation), the lens type (rectilinear or fish-eye, and the focal length), the coverage and the overlap ratio.

Panoramic Image Stitching

The desired output is a 360-degree panorama, which is an immersive image containing information of the full enclosed-sphere scene from one viewpoint inside the sphere. The state-of-the-art stitching pipeline contains three phases: pre-processing, registration, fusion. Camera distortions and colors correction are corrected in the pre-processing phase. In the registration phase, the mapping between the pixels in two adjacent images is defined by a homography matrix, which is calculated by the estimated camera parameters. Homography matrix is generally computed based on pairs of matched points, extracted from the images using a feature detection algorithm and matched according to a matcher method. The estimated homography matrix is pairwise, which makes each homography is independent of others. If the images are stitched from the first to the last, the errors will accumulate, which causes lower visual quality. Therefore, global refinement of the camera parameters that minimize the misregistration is needed, which is named bundle adjustment (Szeliski, 2007; Chen et al., 2019). Knowing the camera parameters, the transformations between each pair of images are known. The images are then projected to a sphere according to the camera parameters, and then the equirectangular projection is used to map the sphere coordinates to plane coordinates for visualization, which is named image warping (Szeliski and Shum, 1997). The warped images are finally blended to a 360-degree panorama in the fusion phase.

A large amount of work has looked specifically at one or another step in the process to improve it, according to different criteria of quality, acquisition or computation time. Among these studies, El Abbadi et al. (2021) brings together a series of comparative analyses of various methods for feature extraction (e.g. SIFT, SURF, KAZE, ORB), point matching and homography estimation. Multiple solution are also proposed to smooth the transition between images by using seam finding or blending approach (Szeliski, 2007; Herrmann et al., 2020).

The presence of moving objects or people in the acquisitions still leads to defects in the result: the presence of artifacts, occlusions, ghosting effects, able to ruin the final composition or to hide some important details in an architecture or artifacts in a museum room... Simple stitching processing of these images does not allow dealing with the whole problem, allowing only to solve the issues in the overlapping parts partially. The state-of-the-art solutions only deal with the problem by having a sufficient number of acquisitions at the risk of presenting some aberrations in poorly covered area (like tearing, ghosting, duplication of recognizable objects or people).

Method

The proposed solution consists of analyzing the pictures in parallel with their acquisition to know whether they should be taken again. In animated site contexts, on the one hand, it is difficult to obtain an image without any moving object; on the other hand, each new contribution makes it possible to obtain new small background areas. The combination of all of these areas, therefore, makes it possible to obtain a completely cleaned panoramic image.

Figure 3 gives an overview of the complete pipeline of the proposed solution.

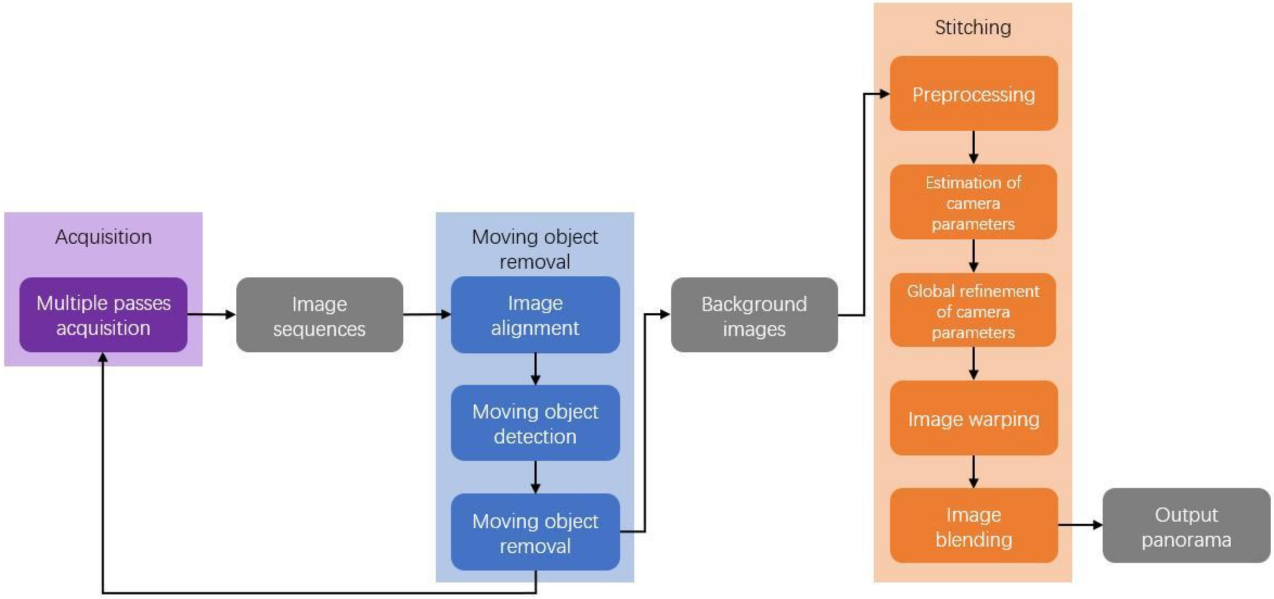


Fig. 3. The complete pipeline to generate panorama with foreground removal (© Zheng Zhang).

The three major steps are: acquisition, moving objects removal, and stitching.

1. Acquisition: datasets are captured pose by pose under control of the robotic head, using multiple passes when a picture contains moving objects, producing an image sequence for each camera pose.
2. Moving objects removal: Assuming that the pixels of the same coordinate are not covered by the foreground objects in all photos, the moving object removal approach can extract background information from the image sequences. The presence of a foreground object in the same picture's part in all the sequences implies the need for a new acquisition.
3. Stitching: After removing the moving foreground objects, there will be pure background images having overlapping parts, and then these images can be stitched to a panorama.

Moving Foreground Removal Approaches

Assuming that the pixels of the same coordinate are not covered by the foreground objects in all photos, the moving object removal approach can extract background information from the image sequences. The key idea is filtering out the foreground pixels and merging the remaining background pixels for each spatial point in the result. Therefore, the pixels at the coordinates (x, y) of each image captured with the same camera pose should correspond to the same spatial point, and the images in the sequence need to be aligned by homography transformation as preprocessing.

The classical approach is the median of images. However, this approach has ghosting artifacts in the area where the foreground objects are denser. A better approach is the foreground mask-based approach to remove the foreground. Some definitions of variables are given as follows for clarity: given an aligned image sequence $I_1, I_2, \ldots I_i, \ldots I_n$, $C_{c,i}(x,y)$ is the value of channel c of the pixel at coordinates (x,y) in image I_i. $C_c(x,y)$ is the value of channel c of the pixel at coordinates (x,y) in the result.

The workflow (Fig. 4) starts with foreground object detection, whose objective is obtaining a binary mask M_i that marks foreground objects for each image I_i in the sequence. $M_i(x,y)$ is the Boolean value at (x,y) in the mask M_i. The set $M_{x,y}$ contains the index of images in which the pixel at (x,y) is the background, i.e., $i \in M_{x.y}$ if $M_i(x,y) = False$. $N_{c,x,y} = \{C_{c,i}(x,y) \big| i \in M_{x,y}\}$, which is the set of values of channel c of unmarked (background) pixels at coordinates (x,y). The background is computed as:

$$C_c(x,y) = \begin{cases} median(\{C_{c,i}(x,y) \big| \, i = 1, \ldots, n\}), & if N_{c,x,y} = \emptyset \\ median(N_{c,x,y}), & otherwise \end{cases}$$

Thus, the pixel values in the output are the median of unmarked pixels at the corresponding coordinates.

This approach can be summarized as extracting all background pixels from the sequence of images; then, the extracted pixels are merged to generate the result. If no background pixels are detected at a place, the value of that pixel is the median of all pixels at that position. Another solution to deal with such presence of a foreground object in the same picture's part in all the sequences is executing a new acquisition at that camera pose.

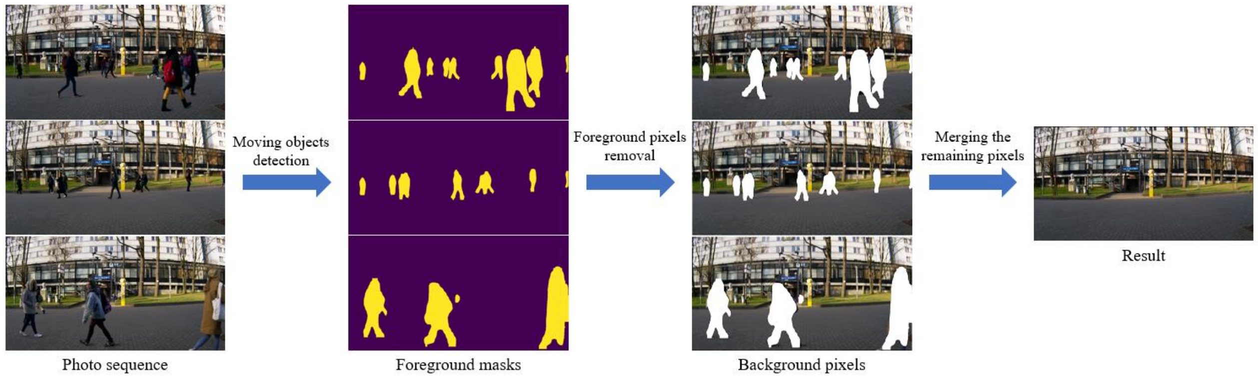


Fig. 4. Workflow of foreground-mask based approach: 1. Moving foreground detection; 2. Foreground masks generation; 3. Pixel merging (© Zheng Zhang).

Depending on the opportunities of acquisition; several scenarios are possible:

- the combination of the images allows to correctly and completely remove the foreground objects; the process then continues with the next step;
- the images acquired are insufficient to treat the problem: either it is possible to make new acquisitions, a new cycle of acquisition and foreground removal is carried out; either new acquisition is not possible (due to limitations of the acquisition time, for example, depends on functional or lighting conditions), an image is then selected to present an entire obstacle in order to give a tangible result.

Moving Foreground Objects Detection

Several foreground detection methods are implemented: Three-frame differencing, MOG2, KNN, YOLO, and Mask R-CNN. Three-frame differencing, proposed by Kameda and Minoh (1996) detects moving objects in an image sequence by calculating the difference between two images, considering a third allows to identify the persistent elements, and therefore differentiate the foreground and the background. Because the proposed approach is executed on discrete images, the three frames do not have to be in chronological order as the original version. The schematic diagram of the novel proposed three-channel version is shown in Figure 5. Assuming there are n photos in the sequence, I_i describes the $i-th$ image. The masks of the first image I_1 and the mask of the last image I_n are generated from I_n, I_1, I_2 and I_{n-1}, I_n, I_1, respectively. Instead of changing the image to grayscale as the original version, the proposed three-frame differencing implementation is applied separately on three channels; a binary closing operation follows the logical 'AND' to reduce the holes, and then the binary masks of the three channels are combined by the 'MAX' operation. If a pixel is marked as a pixel of moving foreground on one channel, the pixel will be marked in the final result.

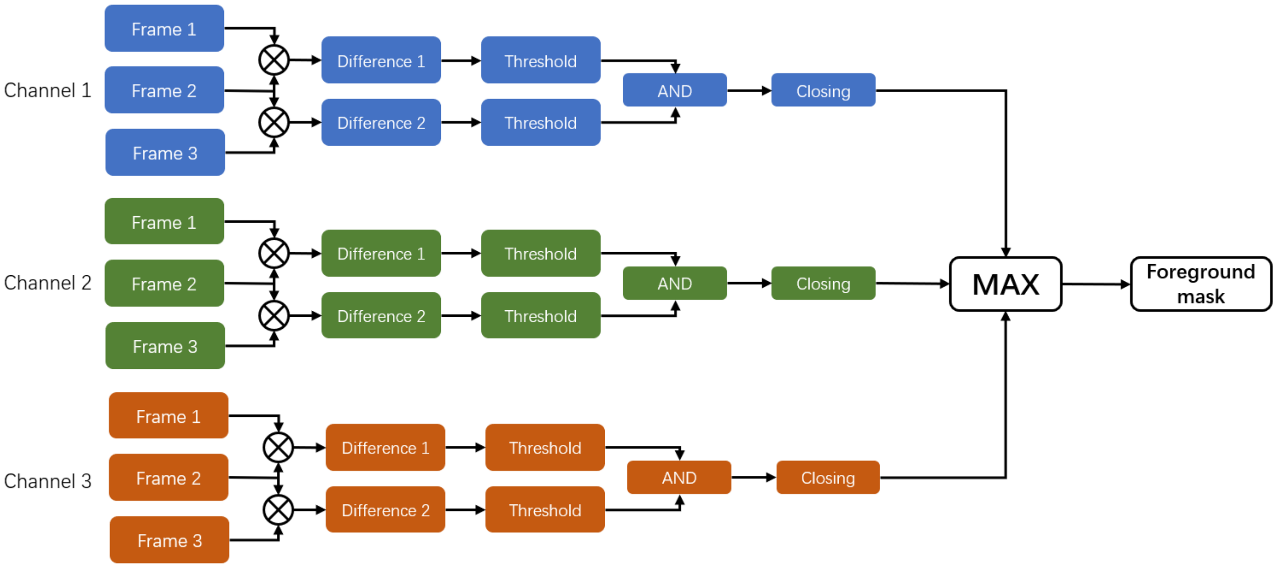


Fig. 5. Schematic diagram of multichannel three-frame differencing (© Zheng Zhang).

The MOG2 (Mixture of Gaussians v2, background subtractor with shadow detection described by Zivkovic (2004)) and KNN (K-nearest neighbors-based foreground segmentation described by Zivkovic and Van der Heijden (2006)) are background modeling methods usually applied to videos and need hundreds-frames initialization. MOG2 is a background subtractor with shadow detection. This approach is a Gaussian Mixture Model (GMM) based algorithm, which builds a statistical background model of the scene. The image to be detected is compared with the background model, and the pixels that do not fit the background model is marked as pixels of a foreground object. The KNN algorithm maintains a fixed-length memory to store the values of the pixels in a period T for each pixel. For a newly arrived frame, if the value of the pixel has more than k neighbors within its neighborhood of radius r in the memory, which stores the historical values, the pixel at the newly arrived frame will be assigned to the background.

Both MOG2 and KNN are designed for processing the consecutive frames in a video, and these model-based approaches usually need hundreds of frames to initialize the model. However, the used image sequence is not consecutive frames, so we need to initialize the background model artificially. Three fast initialization methods are proposed:

- using the median of the images in the sequence to initialize;
- initializing by a series of gamma adjustment of the median;
- pre-feeding the image sequence once, and then feed the image sequence again to obtain the masks.

The best initialization method of each of these three model-based approaches is different. The comparison of varying initializations will be given in the experiments section. The output foreground masks of MOG2 and KNN are followed by dilation operation and closing operation to obtain the optimal masks.

YOLO (You Only Look Once, real-time and end-to-end object detection convolutional neural network described by Redmon et al. [2016]) and Mask R-CNN (Region-based Convolutional Neural Network method with object mask prediction, described by He et al. [2017]) are deep neural networks-based approaches. These two object detection networks can detect foreground objects directly with knowing the class of the foreground objects, e.g., pedestrians and vehicles. YOLO is the most widely used real-time and end-to-end object detection convolutional neural network. It aims to detect multiple-categories objects in the input image. For each detected object, it returns the center, height, and width of the bounding box. The foreground mask is generated by setting the pixels inside the bounding boxes to be True. Object detection of the YOLO yields bounding boxes, so the foreground mask of YOLO is composed of rectangular. That will waste some background pixels around the foreground objects. Therefore, the Mask R-CNN, which can generate a segmentation mask, is brought to be compared with YOLO. Since YOLO and Mask R-CNN cannot detect the shadow of objects, a shadow mask is added to the object detection mask by identifying the shadow of moving objects using MOG2. The final result is obtained by binary ‘OR’ operation between the object detection mask and the additional shadow mask.

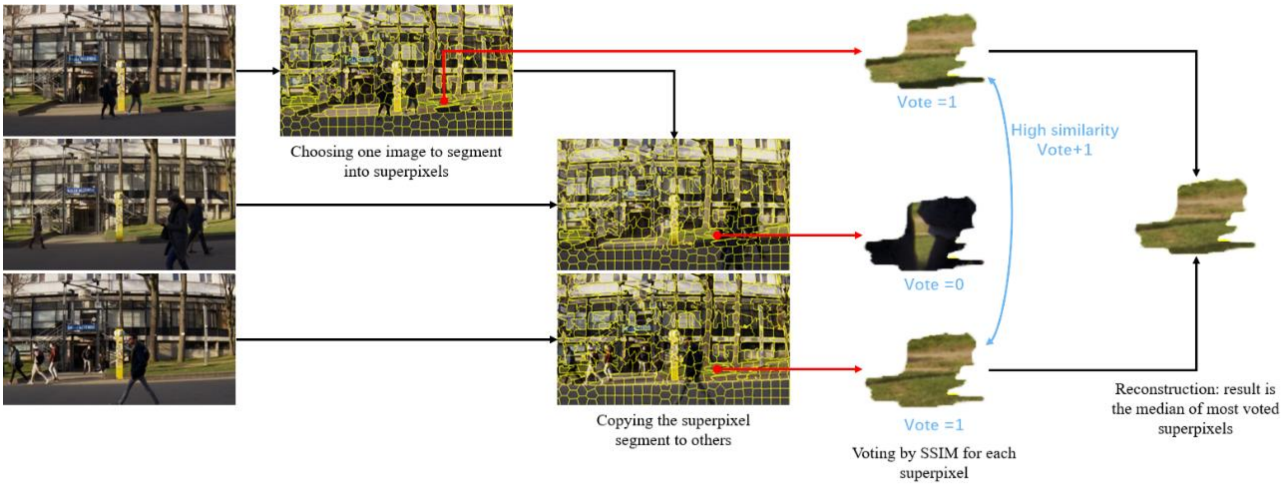


Fig. 6. Superpixel voting approach. An image is segmented into superpixels and this segmentation is copied to others. Then resulting superpixel is generated from a cluster of similar superpixels (© Zheng Zhang).

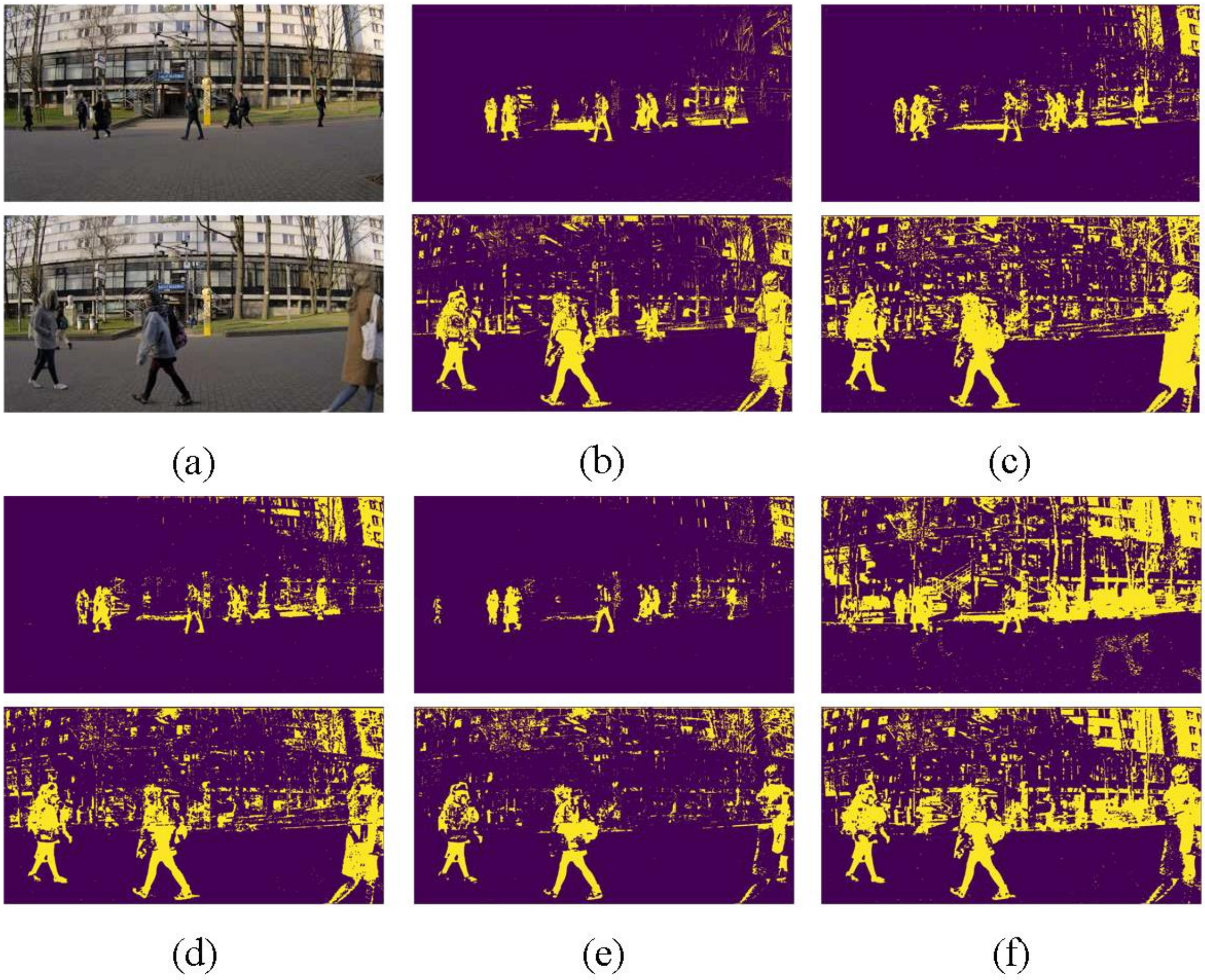
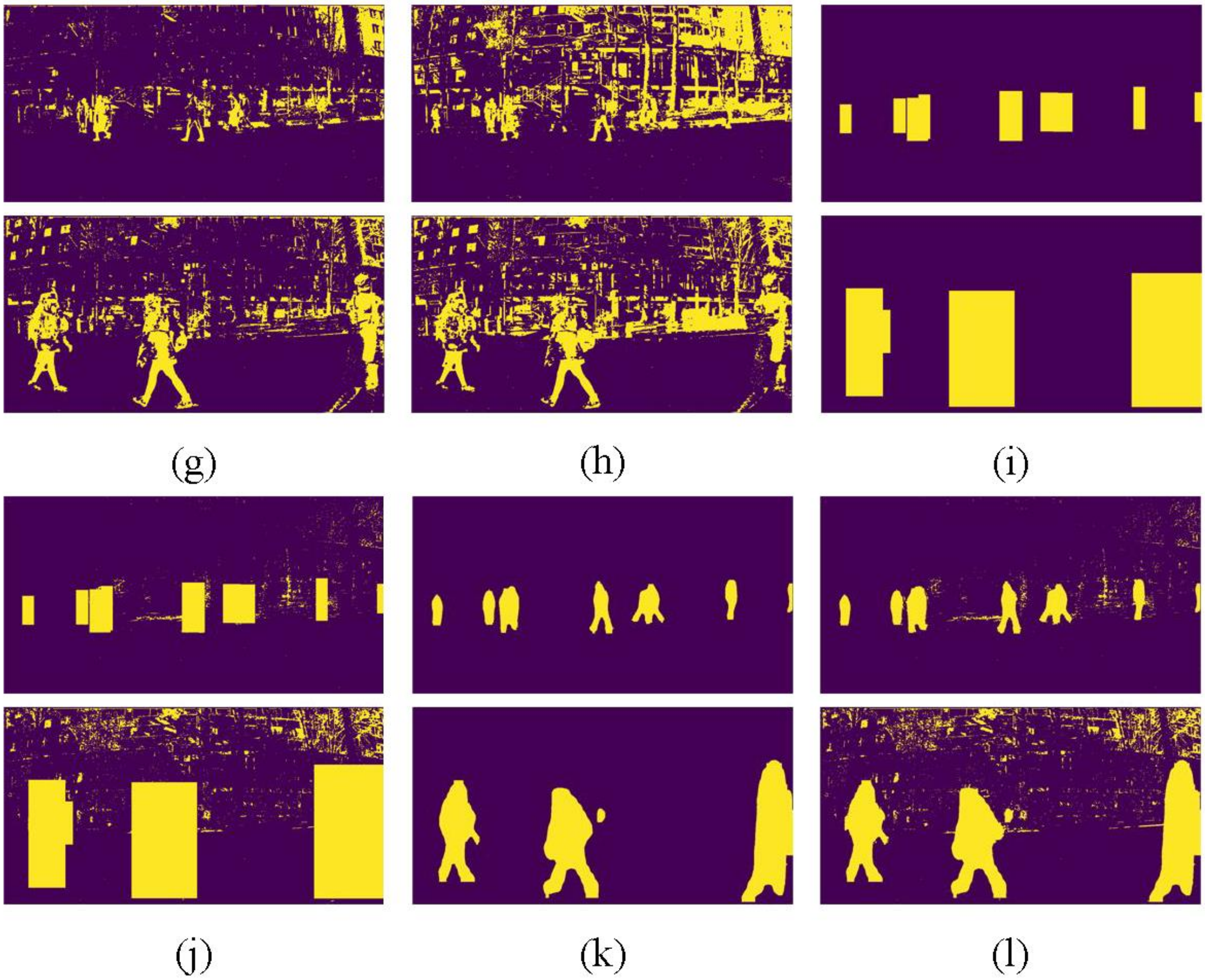


Fig. 7. Examples of obtained masks for two picture following described methods: (a) Training images, (b) Three-frame differencing, (c) MOG2 (median initialization), (d) MOG2 (training images initialization), (e) MOG2 (gamma initialization), (f) KNN (median initialization) (© Zheng Zhang).

Besides the foreground mask-based approaches, a superpixel-based method which is inspired by Su (2018) is created. Superpixel is a cluster of adjacent pixels that share similar visual properties, i.e. color, texture, etc. The proposed superpixel voting procedure is summarized as follows, and the schematic diagram is shown in Fig. 6:

1. Choosing a frame with a few objects and smoothing the frame using the median filter.
2. Segmenting the image into superpixels by simple linear iterative cluster (SLIC) algorithm, proposed by Achanta et al. (2012). The approximate number of segmentations is the hyperparameter of SLIC.
3. Duplicating the superpixel segmentation to all frames.
4. Computation of structural similarity (SSIM) for each pair of corresponding superpixels between the current frame and every other. If the SSIM larger than 0.65, the votes of this superpixel increase by one.
5. Reconstruction of the result: the result superpixel is the median of the superpixels with the most votes; the image is reconstructed by jointing all the result superpixels. Because of the commutativity of SSIM, there must be more than one superpixel having the most votes.



(g) (h) (i)

(j) (k) (l)

Fig. 8. Examples of obtained masks for two picture following described methods: (g) KNN (training images initialization), (h) KNN (gamma initialization), (i) YOLO, (j) YOLO with shadow detection, (k) Mask R-CNN, and (l) Mask R-CNN with shadow detection (© Zheng Zhang).

All the approaches above will be evaluated in the section of experiments. Figure 7 and 8 gives examples of masks obtained according to these different methods.

Results and discussion

This section demonstrates the experimental results of the moving object removal approaches and the panorama constructed from the pure background images. Different approaches are evaluated quantificationally and analyzed.

The experimental dataset is captured by the fish-eye lens pose by pose under the control of the robotic head, using multiple passes, producing an image sequence for each camera pose. Each acquisition pass consists of several camera poses, and multiple passes are executed at the same capturing position, i.e., there is an image sequence for each camera pose in the dataset. To extract background information from these image sequences, the first requirement for the acquisition of data is that there are enough photos for each spatial point to extract the background from. The second requirement is that each pair of adjacent photos has an overlap so that the photos can be stitched to a panorama.

To realize our testing datasets, we used a Panocatcher Maestro 4HD heavy-duty, full-size, dual-axis robotic head with a Zenitar 16mm f/2.8 fish-eye lens mounted on a Nikon D810. The robotic panoramic head offers the possibility to make each time the same shots at almost the same determined rotation angle. The state-of-the-art stitching pipeline (Fig. 3) is used to obtain the panoramas.

The ground truth should be a pure background without any foreground objects. If the dataset is captured in a place with high traffic, it will tough to find an opportunity that no one passes by. A solution to address this problem is proposed: taking out the photos that have small amounts of moving objects as a test set, the others who have plenty of moving foreground are put in the training set. The ground truth is the median image of photos in the test set, which is an optimal background. Some pedestrians are added manually to part of the training images to create critical scenarios.

The used metrics are root-mean-squared error (RMSE) and structural similarity (SSIM). RMSE can measure the average error. However, sometimes human eye judgment may be different from numerical error, so the structural similarity (SSIM) is used to consider the luminance, contrast, and structure comprehensively. For the RGB image, the MSE of each channel is summed and divided by three.

The quantitative evaluation is shown in Table 2. The result of the median approach has lots of ghosts, and the ghost problem arises in the areas where have moving objects frequently. Most of the foreground-mask-based approaches perform better than the median. The performance of foreground-mask-based approaches depends on the quality of the masks, so the two CNN-based approaches outperform others with the most precise masks. The masks of YOLO are composed of filled bounding boxes whose edges may leave some traces on the result. The masks of Mask R-CNN are in line with the shape of the objects, which will not waste background information and will generate a cleaner result.

Table 2. Quantitative evaluation, the bold values are the best in the metric.

Algorithm	RMSE	SSIM
Median	6.5862	0.9127
Three-frame differencing	7.0378	0.8982
MOG2 (median init)	7.1981	0.9051
MOG2 (training images init)	7.2795	0.9064
MOG2 (gamma adjusted medians init)	6.4634	0.9093
KNN (median init)	7.4758	0.8891
KNN (training images init)	7.6481	0.8962
KNN (gamma adjusted medians init)	8.0399	0.8948
YOLO (without shadow detection)	6.0042	0.9179
YOLO (with shadow detection)	6.1213	0.9101
Mask R-CNN (without shadow detection)	***5.9205***	***0.9182***
Mask R-CNN (with shadow detection)	*6.0105*	*0.9115*
Superpixel voting (1000 segments)	6.8101	0.9091
Superpixel voting (2000 segments)	6.7598	0.9076
Superpixel voting (3000 segments)	7.0700	0.9049

The defects of the superpixel voting approach are in the form of patches, which are in the shape of the superpixel segment. The number of segments determines the performance: too few segments will increase the error; too many segments will be time costing. Another advantage of YOLO and

Mask R-CNN is that they do not require multiple frames to detect moving objects, allowing the problems detection in parallel with acquisition. In conclusion, the Mask R-CNN approach is the most accurate, and the shadow can be detected by MOG2.

Conclusions

The main contributions of this work include: (1) data acquisition method and semi-synthetic dataset generation method for evaluation; (2) the initialization approaches to apply the background modeling approaches on a sequence of few pictures; (3) proposing, implementation and evaluation of the moving foreground removal approaches. The image sequence is aligned and split into a test set and training set, and the images in the test set are used to generate ground truth. Synthetic foreground objects are added to the training set for critical evaluation. All the proposed moving object removal approaches are evaluated and analyzed. Best results are obtained combining both approaches: Mask R-CNN for object detection and MOG2 for shadow detection

The experimental results (Fig. 1 and Fig. 10) show that the ghosting artifacts and the foreground objects have been effectively removed using the approach in this paper.

Fig. 10. Comparison of panorama with traditional (top) and proposed method (bottom) (© Zhang Zheng).

Funding

The project did not receive external funding.

Conflict of Interests Disclosure

No conflicts of interests have been declared by the authors.

Author Contributions

Conceptualization: Arnaud Schenkel
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Deep Learning for More Expressive Virtual Unwrapping

Learning Transformations from Tomography to Other Modalities

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Keywords: *Machine Learning—Virtual Unwrapping—X-Ray Microtomography—Text Recovery*

CHNT Reference: Parsons, S., Gessel, K., Parker, C. S., and Seales, W. B. (2022). 'Deep Learning for More Expressive Virtual Unwrapping', in Börner, W., Rohland, H., Kral-Börner, C. and Karner, L. (eds.) *Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020*. Heidelberg: Propylaeum.
doi:10.11588/propylaeum.1045.c14501

1 Introduction

This paper presents the general use of deep learning for texturing[1] within the virtual unwrapping model. Virtual unwrapping is a software pipeline for the noninvasive recovery of texts inside damaged manuscripts or scrolls via the analysis of tomography (Seales et al., 2016) and consists of three stages (Fig. 1). Segmentation isolates pages or layers as surface meshes, texturing paints these surfaces based on the local neighborhood in the tomography, and flattening produces legible images from the folded, rolled or warped meshes. The pipeline allows for the recovery and restoration of a variety of otherwise lost or hidden heritage objects.

The output of the virtual unwrapping pipeline is an image revealing the contents of a page or layer inside the scanned volume (Fig. 1c). Segmentation determines where each point on this surface originates in the volume, and flattening determines the layout of the final visualization. Texturing is the process responsible for rendering or painting the image itself onto the surface, guided by the original scan. It is critical that texturing reveal something of interest, as segmentation and flattening are of no use if the resulting image is featureless.

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[1] "Texturing" here means the application of a 2D image to the surface of a 3D mesh, as with "UV mapping" or "texture mapping," not "texture" as in the physical shape, consistency or feel of a surface.

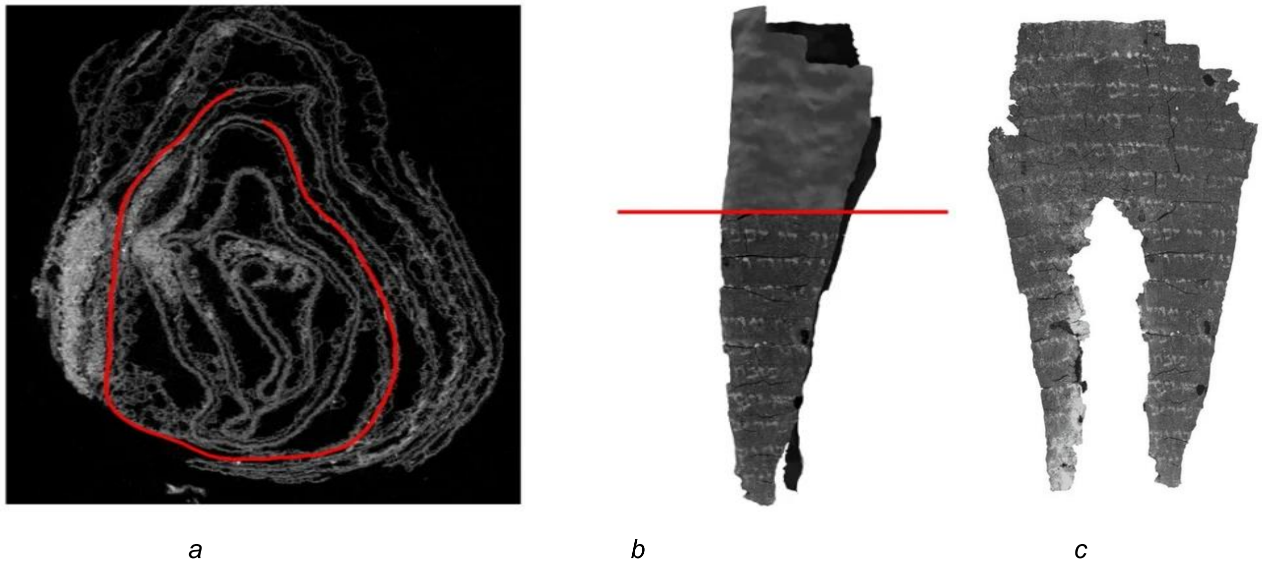


Fig. 1. Virtual unwrapping a) Segmentation isolates layers in the volume; b) The result is a 3D mesh of the shape of a layer. This mesh is then "textured" based on some function of the tomography; c) Flattening produces a 2D image. Virtual Unwrapping of the Scroll from En Gedi, images by S. Parker, EduceLab/The University of Kentucky. CC BY-NC-ND 4.0.

Traditionally, texturing methods have been based on simple functions designed to extract some information directly from the tomography. For example, Figure 1c is obtained pixel by pixel by examining a neighborhood in the 3D scan around a particular point of interest and selecting the maximum intensity observed inside that neighborhood. This value is directly plotted on the output image. The image can be interpreted as a modified visualization of raw tomography data. What appears as a bright spot in the tomography likewise appears brightly in the image. Where this intensity difference corresponds with a desired signal, as above where the ink appears brighter in X-ray than the surrounding substrate, the image reveals the text.

It is not always the case, however, that the X-ray response readily provides useful texturing information. For example, carbon ink is not easily distinguished in tomography. Additionally, the scholar may not wish to see an image directly corresponding to the X-ray response for other reasons. It may be advantageous to look at a color image, as if the surface had been photographed. Parker et al. (2019) addressed these cases by creating neural networks to learn the carbon ink signal directly and to learn to recreate the page's color appearance.

This work further expands the generalization of the texturing stage. Neural networks can be trained to detect not only carbon inks, but any desired signal in tomography data. Additionally, they can output not only color images, but any modality or form desired by the scholar. The contributions of this paper are as follows:

- A conceptualization of texture mapping as a general function, perhaps learned, mapping tomography to any modality is established (Section 2).
- Several technical improvements to the previous neural network approach are discussed (Section 3).
- This framework is applied to new data, yielding state-of-the-art results (Section 4).

2 Expanding the Texturing Concept of Virtual Unwrapping

The heritage scientist and scholar presently have a wealth of tools at their disposal. For example, the pages of a manuscript could be photographed for the creation of a digital facsimile; imaged under multi-spectral lighting to reveal faded pigments; or undergo X-ray fluorescence (XRF) studies to analyze the ink composition.

Unfortunately, in the case of damaged or fragile materials, the use of these imaging tools is precluded for conservation reasons, and the heritage scientist is instead restricted to non-invasive tomographic imaging methods. This limitation is a significant constraint, primarily for the changes in dimensionality, visualization, and resolution. Virtual unwrapping overcomes these limitations by extracting the layers from the volume and presenting them in a more familiar arrangement. But a second limitation must also be overcome, involving the modality of the images and the information they convey. Note that Figure 1c clearly reveals the text but may not resemble a modality familiar to the manuscript scholar, as they are viewing essentially a projection of X-ray.

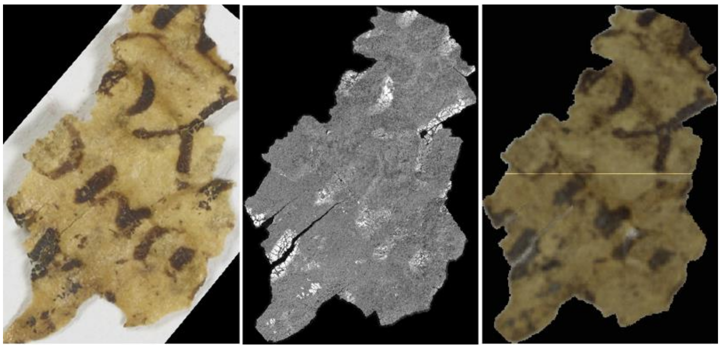
One can imagine this is not the scholar’s ideal visualization of the pages. The key principle of this work is that texturing in virtual unwrapping can be generalized to simulate any modality. Though the scholar is constrained to acquire tomographic images, in this case X-ray, the visualization of the resulting data can take on any form.

Machine learning provides the ability to learn virtually any transformation for which training data can be acquired. The training data is acquired using reference materials which have exposed surfaces containing the signal of interest, usually text. To continue the example above, consider a manuscript which cannot be opened but has exposed writing on the top surface. This top page can be imaged using any traditional tools, and the entire manuscript can then be scanned with tomography. A mapping can thus be learned between tomography and these modalities. The real benefit is when this mapping is then used to visualize the hidden pages as if they had been scanned using spectral photography, XRF, etc.

3 Technical Improvements to the Neural Network

The initial neural network was trained to output a value representing a single pixel of the output image (Parker et al., 2019). To create an output image, a subvolume corresponding to each individual pixel location was fetched and then fed to the trained network. The resulting output was stored one pixel at a time in the output image. This approach was a breakthrough for being the first to reveal carbon ink in tomography, but left room for additional improvement. First, the method is slow and scales poorly to the high-resolution images that are often desirable. Second, independently processing adjacent pixels ignores their spatial correlation. As a result, output images can appear noisy where they should be smooth. In this work the use of 2D neighbourhoods as labels and outputs is explored. The neural network is trained to take a subvolume as input and output a label corresponding to the region of the output image spanned by that subvolume. The output images can be generated more efficiently this way and are additionally smoother. This neural network can be considered a hybrid architecture similar to a 3D U-Net contracting path (Çiçek et al., 2016) with a 2D U-Net expanding path (Ronneberger, 2015). Additional refinements to the performance at inference time have also been developed, such as inference augmentation with prediction averaging and output region overlap with blending. Finally, alternative loss functions and their respective performance improvements have been explored.

4 Results on the Morgan M.910 Manuscript



a b c

Fig. 2. Morgan M.910 Manuscript fragment a) Photograph; b) From Seales et al., 2016; c) Proposed. M.910 Fragment, photograph and renders by S. Parker, K. Gessel, S. Parsons, EduceLab/The University of Kentucky, CC BY-NC-ND 4.0.

Figure 2 shows the results of a neural network trained to reproduce an RGB photograph from tomography data. The image on the right, generated purely from X-ray tomography, highly resembles the real photograph (left). This is a much more natural way of visualizing the tomography compared with the previous method (center).

5 Conclusion

This work has presented a general approach to texturing within virtual unwrapping that allows the scholar to generate virtually any visualization for which there is training data. This framework allows virtual unwrapping to become a powerful lens for looking inside tomographic scans, magnifying or revealing previously buried signals. Along with technical refinements, these concepts are enabling state-of-the-art results on real data.

Ongoing and future work.

There are ongoing efforts to improve the ability of the trained networks to generalize across various scans, so they can be trained on one set of data and then used to reveal the contents of entire scans for which the network has never seen labeled data. One initial approach to be tried is the use of autoencoder regularization for semi-supervised learning. These methods are also contingent on accurate segmentation. Other work focuses on leveraging deep learning to improve the segmentation performance.

Acknowledgements.

The authors would like to thank Dr. Paul Dilley from the University of Iowa for the study of revealed texts; Maria Fredericks, the Sherman Fairchild Head of the Thaw Conservation Center at the Morgan Library & Museum and her conservation team who made the scans possible and worked with us to ensure the manuscript’s safety; MicroPhotonics for the use of the micro-CT equipment to scan the manuscript; Raj Manoharan, Seth Hogg, and Benjamin Ache of MicroPhotonics Inc. for micro-CT scanning services and consultation; and Christy Chapman for editorial support and input.

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Round Table:
Citizen Science Go!

Taking citizen participation (one step) further

Elisabeth MONAMY | Sigrid PETER

Call

Elisabeth MONAMY, Archeomuse + Universität Bern
Sigrid PETER, Association for preservation and research of castle “Ried am Riederberg” + Archeopublica)

Keywords: *Citizen Participation—Fake News—Political Engagement—Archaeology*

After the first approach to citizen participation in archaeology last year asking if it was needed and how it could help archaeologist in their daily work, this round table wants to reach further. Where can citizen participation be of a help without seeming obvious? How can citizen participation help counteract fake news? Spreading the word through citizens science could be easier understood than scientific talks by professionals and therefore help avoid propagation of fake historical information. Which place and positioning does social media have in diffusing widely understandable information? What are the dangers of these short and very superficial channels? Or how can citizen scientists be encouraged to dare to submit a project although the administrative steps seem discouraging, especially in Austria? How can citizen participation in archaeology be a way of political commitment and trying to make a change? Would new technologies like LIDAR, apps or even VR and AR used by many people for their daily work be of a help? Archaeologists won’t need to learn to many new skills and get a full package: manpower including knowledge. To what extend can open data and online communication between archaeologists and interested parties function when the world is at a standstill? How can networked research and interaction with lay people be successful using new technologies?

During the round table 2020 we would like to show on one hand that citizen participation in archaeology can be channelled to reach a common goal or interest but on the other hand that interested citizens should stop moaning and stand up.

Everyone who would like to contribute to this round table is welcome to submit a short (impulse) lecture. Present your own citizen participation project, share your experiences about involving people from different backgrounds – or point out failures.

We invite the widest range of people – up from professionals in all related disciplines to amateurs and citizen scientists of all disciplines to participate in the discussion. The round table consists of many different short impulse lectures (~10 min) and a discussion in which all participants and listeners are invited to actively engage in.

Engagement with classical archaeology and the ethics of contemporary clothing production

Exploring the interface of citizen engagement through technologies at the London Bloomsbury Festival 2020. Digital engagement through contemporary fashion design

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Keywords: *Digital—Engagement—Fashion—Archaeology—Ethics*

CHNT Reference: Frampton, C. (2022). ‘Engagement with classical archaeology and the ethics of contemporary clothing production: exploring the interface of citizen engagement through technologies at the London Bloomsbury Festival 2020’, in Börner, W., Rohland, H., Kral-Börner, C. and Karner, L. (eds.) *Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020*. Heidelberg: Propylaeum.
doi:10.11588/propylaeum.1045.c14503

Setting the scene

The Atelier Tammam Sustainable Couture Roving Fashion Show in London presented a catwalk of sustainable fashion, in October 2020. This was part of the Bloomsbury Festival, which is an annual showcase of culture in an area of central London. The Tammam show combined various aspects: sustainable fashion practice, engagement with heritage and the environment of London, the models wore facemasks which were part of the collection, essential in the era of COVID. Online information about the show stated that it ‘selected to pass some of Bloomsbury’s iconic sites’ this included the British Museum, where ‘ancient textiles and draped statues have all given influence to Tammam’s couture practice’ (Bloomsbury Festival, 2020). The photograph Figure 1 documents the show outside the British Museum. Tammam promotes ethical practice and in the publicity invited interest-ed people to follow the process of ethical clothes production through Instagram. People were en-couraged to upload their photos to social media (Bloomsbury Festival, 2020). After the 2020 show, documentation was posted on internet social media by citizen participants, and on the Tam-mam and Bloomsbury Festival digital platforms. This included a film documenting the models walk through the streets of London which showed on the Bloomsbury Facebook channel (Bloomsbury Festival, 2020), which featured use of technologies documenting the project i.e. cameras, mobiles and tablets by models, citizen participants and official media personnel. It showcased a colourful collection; one piece a draped dress in grey silk. The caption for a Tammam Instagram post with a photograph of this item showcased outside the British Museum stated that this was ‘cool steel #peacesilk chiton’ that the ‘fabulous silk skims the body like water’, see the photograph Figure 2. (HOUSEOFTAMMAM, 2020). A type of classical garment, Koda wrote that a chiton is a ‘chemise-like shift … Constructed of two rectangles of fabric … seamed together’ (Koda, 2003, p. 219).

Fig. 1. Atelier Tammam Sustainable Couture Roving Fashion Show (2021) photograph taken by C.Frampton.

The Creative Process

In an interview after the event, Ms. Tammam said that the initial idea was for the show to take place in the British Museum, however this idea was dropped because of the lockdown. About the creative process of taking inspiration for the design of new garments from various historical eras, she spoke about her influences including 1940s vintage; she developed her sustainable fashion practise through working with historical methods. She said that ‘the idea of Greek draped dresses… came from this idea of zero waste pattern cutting which obviously is… one way to be very sustainable’. She had learnt about the Greek chiton stye and recognised this in classical sculpture. About the contemporary use of historical methods, she said that:

‘I think there’s a lot to be said for how clothing was made in the past, as opposed to very mass produced fast fashion … the way we try and make clothes is going backwards into the time when things were made for you as an individual… In terms of sustainability it makes so much more sense in terms of supporting the crafts people who are making it … I actually think it’s the future’ (Tammam, 2020).

About the relationship of her practice to a cannon or history of fashion inspired by classical sculpture’, Ms.Tammam said that ‘Fashion is cyclical, it goes round and round’, in the 1930s Greek style draped dresses were in style. The online information about the 2020 show included a photograph of a showcase of models posing on a staircase wearing white dresses with classical design influence (Bloomsbury Festival, 2020). It was from a Tammam roving couture fashion show 10 years ago, taken at St.Pancras station, London. This referenced the Tammam archive and gave a taste of Tammam style (Tammam, 2020). About the 2010 show, its documentation and photographic archive, Ms.Tammam said that interaction through social media such as Twitter wasn't significant, photos were stored on a hard disc, at that time there wasn't an online archive (Tammam, 2020).

To quote recent related academia, an essay 'Material form and the dynamic archive' discusses ideas about historical archives of photographs, proposing to 'stop thinking of photographs and their archives simply as passive "resources"', rather 'as actively "resourceful" – a space of creative intensity, of ingenuity, of rich historical force' (Edwards, 2019, p. 528). With the reuse of archival photos to promote a recent show, and the encouragement of photography with social media, Tammam facilitated dynamic engagement with its' house archive, also with historic reference to classical influence on fashion, through digital technology.

Citizen engagement, part of the Bloomsbury Festival

About citizen engagement, Ms. Tammam said the annual Bloomsbury Festival is 'very much about engaging the local community'. The encouragement of engagement with the show through technologies related to the development of understanding about Tammam and its locale; including QR codes and being able to link to the festival site (Tammam, 2020). A short film on the Bloomsbury Festival YouTube channel featured a clip of the fashion show with the models walking past a red telephone box- a classic symbol of London, the shots allowed the viewer to appreciate the show within the context of the festival which included a range of art forms. Text at the end of the film states that the festival was successful despite the challenging times (Bloomsbury Festival, 2021). A page with information about the festival report on the festival website features statistics about records of participant engagement including digital engagement for the whole festival, for instance records of '11,106 Social media followers' (Bloomsbury Festival, 2020).

Fig. 2. Atelier Tammam Sustainable Couture Roving Fashion Show (2021) Stuart Keegan for Bloomsbury Festival.

Author Contributions

Writing – original draft: Frampton,C.

Writing – review & editing: Frampton,C.

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Young people convey history

Or how young citizens take the initiative

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Keywords*: Citizen Participation—Teenagers—Scavenger Hunt—History of Vienna*

CHNT Reference: Monamy, E. (2022). 'Young people convey history. Or how young citizens take the initiative', in Börner, W., Rohland, H., Kral-Börner, C. and Karner, L. (eds.) *Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020.* Heidelberg: Propylaeum.
doi:10.11588/propylaeum.1045.c14504

Introduction

Getting children and young people interested in archaeology and history is not very difficult but keeping them interested is not always an easy task. Who is to blame? History lessons consist mainly of data, facts about wars and conquests. Terms such as pharaoh, pyramids, Gauls, Romans or even treasures magically attract our younger fellows, but this enthusiasm evaporates very quickly, if they have to learn kings and ruler's reigns by heart during their school years.

The project

This project starts precisely here, in order to keep children and young people interested in archaeology and history and to make history lessons livelier. It is also about bringing the everyday life of individual epochs closer. A further aim was to show that interested teenagers can take part in the mediation of historical topics themselves without a lot of instructions and accordingly be a part of citizen participation in archaeology.

The project was carried out in a class of the 3rd secondary school level of the Lycee Francais de Vienne in history lessons. The aim was to create a digital and analogue scavenger hunt for young people of the same age to tell the history of Vienna from different perspectives and topics. The class was given an introduction by an archaeologist and their history teacher professor on the general conditions, such as which epochs in Vienna are better excavated and which are less well known, or how to set up a fascinating and exciting puzzle rally, how to write short and concise texts. In addition, playing a puzzle rally on the app "Actionbounds" was a good way to get to know the hardware works, since it was also used for the project. This app specializes in scavenger hunts. The professor and the archaeologist were available during the whole project period. However, the students had to take care of the topics and contents themselves. The result was a scavenger hunt through ancient Vienna, which was designed by 13-year-olds and meant to be for other teenagers. There were new insights and unknown knowledge about Vienna's history far away from the usual tourist attractions. This aspect made it thrilling for the pupils to take part actively in the history class.

The students were divided into small groups that worked on the individual stations. For this, they chose thought of an epoch and a place in Vienna where there is something to see or discover about this epoch. Then they had to work out background information, descriptions, tasks and/or questions and their answers as well as their answer types (photo with location, multiple choice or free text) and the number of points the user would get. The epochs were influenced by their history program for this school year. It ranged from prehistory to the 1st World War with an emphasis on Roman times and beginning of the Middle Ages in and around Vienna.

Conclusion

In the end, the students had a finished historical treasure hunt, which they proudly presented to their classmates, families and friends and got a deeper insight into the history of Vienna. The project was part of the school evaluation, which means that their invested time and strength paid off their grades. Apart from this, the teenagers learned how to transmit historical information in an easy but still accurate way and that the language used was as important as the content. At the beginning, not all students were excited about the project, but they soon realised that learning and mediating history was not as boring as expected.

For the archaeologist, it was a very captivating insight to how youngsters see and perceive their historical surroundings. The epochs and places to visit during this scavenger hunt chosen by the pupils were interesting and enabled a view from a non-archaeological professional perspective. Of course, some typical and well-known places to see in Vienna have been integrated but the pupils made a lot of research about antique sites and / or finds from Vienna.

This project showed that even youngsters are able to create themselves a game about the Viennese history for same aged. They were channelled by an archaeologist, but it was their merit. This is also a way of citizen participation.

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Round Table: Documenting, Digital Restoring and Recontextualizing. (Comparing experiences)

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Call

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Keywords: *3D models—photogrammetry—virtual reality—public archaeology—communication strategy*

This Round Table will be an opportunity to take stock of the researches and experiences put in place by archaeological museums to recreate the context from which works of art come from. Coming from excavations often conducted in the Nineteenth and early Twentieth centuries, most of the archaeological finds exhibited in museums have great difficulty relating to an increasingly demanding public, more and more expecting the use of virtual and augmented reality, as a preferred medium to meet the past. This RT wants to compare a series of (digital) experiences by which museums try to bring the public of non-professionals closer to the knowledge of the past but above all to the recognition of the contexts of origin.

Usually the amount of scientific data acquired by researchers is of considerable importance: now we need to start a debate on how to use these data proficiently, in order to reconstruct the story of the finds and make it available for collective knowledge. It is now a consolidated practice that after analytical and archaeological studies, systematic photogrammetric campaigns transform objects into digital resources: 3D models obtained offer an unmissable opportunity to rewrite events and collecting history. It is not only focusing in terms of material and scholarly knowledge of the object in question, but also the story from the moment of discovery to the display in museum rooms, chronology that also includes all the restoration phases to which the same objects have been subjected. What happens to items on display? If museums work hardly with the goals of digitally documenting, restoring, and recontextualizing archaeological finds, are they also able to evaluate how much their commitment reaches the various audiences?

Digital is a challenge museums can’t miss, not only to find new physical-technical indicators but even merely profitable and quantitative: 3D modelling, digital restoring and recontextualization can give museums a chance to open the Past to whoever in need, keeping firm standards of being both a physical place but also “systems of relationships”, subjects to constant changes in space and time: their function cannot therefore lie “in the arithmetic of profit”, but rather in its continuous function as the engine of memory and training. This RT will therefore examine some experiments trying to evaluate, given in hand, actual benefits in terms of intellectual understanding, attendance of the place where they reside or where virtual models are allocated, and finally, socio-economic implications that this approach entails.

Research, museums, audiences

The experience of the MemO Project to increase the accessibility of archaeological collections

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Keywords: *Archaeological Museums—3D Models—Memory of Objects—Serious Games—Database*

CHNT Reference: Zamparo, L., Faresin, E., and Zilio, D. (2022). 'Research, museums, audiences: the experience of the MemO Project to increase the accessibility of archaeological collections', in Börner, W., Rohland, H., Kral-Börner, C. and Karner, L. (eds.) *Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020.* Heidelberg: Propylaeum.
doi:10.11588/propylaeum.1045.c14506

The problem of objects without context and archaeological collecting: a comparison between research, museums and audiences[1]

Each object carries a memory. It is the trace of those who manufactured it, those who marketed it, and those who used it. An archaeological heritage also holds traces of its deposition, the space in which it was left to rest and the passage of time. This object, however, can also connaturate with a second or third life, with the creation of new memories. Today as centuries ago, these moments can be determined by the discovery of the artefacts, their study and exhibition, perhaps in a museum, or their trade and grouping within private collections.

From the mid-eighteenth century on in Italy, the work of scholars has allowed the establishment of the current archaeological discipline and the most innovative conservation techniques, the drafting of the most strict regulations for the protection of Cultural Heritage and the dissemination of a taste for the ancient that remains today. However, the incredible discoveries above all between Rome, Pompeii and Herculaneum led to the start of a deep and rooted, in the European culture of the time as in the current, desire to possess these objects, incredible documents of a centuries-old history. Alongside legitimate collections, some phenomena take shape, such as clandestine excavations (and the consequent illicit trafficking of cultural goods) or falsification. Over time, this implies the intertwining of true and distorted stories. Stories that can confuse an inexperienced reader and that often deceive the professionals themselves.

Although they are phenomena to be contrasted as illegal and undermining the very idea of Culture, they must be studied for their multiple cultural (historical, artistic, archaeological), social and economic nature (Baggio et al., 2019). The fake object can narrate the technical methods for its production and point out the idea of "ancient" transmitted in various societies. Furthermore, in the eyes of

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[1] Written by Luca Zamparo

many, the object isolated of its context of origin risks losing its importance, as if it were losing its archaeological nature: instead, it still contains a whole memory that nobody can ever steal from it and that only professionals can, once again, bring out to promote and spread a legal and authentic culture.

Based on these considerations, the MemO Project, “The memory of objects. A multidisciplinary approach to the study, digitalization and value enhancement of Greek and South Italian pottery in Veneto”, coordinated by the Department of Cultural Heritage of the University of Padova and supported by the Fondazione Cassa di Risparmio di Padova e Rovigo. The MemO Project, in addition to investigating the spread of Greek and South Italian pottery in ancient and contemporary times in Veneto, has launched an intense campaign of recognition and digitalization of the material present in the regional territory, thanks to the collaboration of 14 different museums, merged into an open-access database explicitly created for research (universities), management (museums) and pleasure (wider audience) purposes. Furthermore, thanks to this impressive material, the MemO Project team is creating the serious game FakeMuse, a tool to make known the authentic archaeological material present in Veneto and to spread a Culture of Legality in the historical-artistic and archaeological field.

Making the invisible accessible: 3D modelling for archaeology[2]

In Digital Humanities, the term “project” takes an operational approach: it involves planning, managing of resources, and the collaboration among scholars of quite different disciplines, leading, in turn, to new interactive and experimental research. Moreover, a project is an activity that “projects” something that, at the very moment, does “not exist”. On this ground, the research project here presented applies methods and hardware belonging to the field of engineering known as Reverse Engineering, using a structured light system scanning instrument, on Greek and South Italian pottery. The advent of information technologies has substantially eroded the gap between humanities and scientific applications and brought on a growing concern for preserving and enhancing what is currently defined as the Digital Heritage. Digital models, in particular, are complex projective information capable of drawing out aspects of an artefact not visible to the naked eye from potentially endless viewpoints.

The acquisition of the objects was performed by taking a set of partially overlapping range scans to acquire many shots and to produce the so-called range maps with geometry, topology and RGB information (Fig. 1). These range maps were processed to convert the data encoded into a single, complete, non-redundant and optimal 3D representation (a triangulated surface). The processing phases (usually supported by standard scanning software tools) are:

- Range map alignment, to put all the single range maps into a standard coordinate system where all the scans lie aligned on their mutual overlapping region.
- Range map merger (or fusion) to build a single, non-redundant triangulated mesh.
- Mesh editing to improve the quality of the reconstructed mesh (Faresin and Salemi, in press).

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[2] Written by Emanuela Faresin

Fig. 1. A structured-light 3D scanning was used to issue a geometric model of micrometric resolution in all its parts. The object was measured with 10 µm accuracy using an automatic turntable (© E. Faresin)

Legality Education and Museums: the Serious Games[3]

In order to spread the issues of legality education in the archaeological field, and the subject matter itself, the design of a serious game (Michael and Chen, 2006) inside the MemO Project has been included.

For the reasons, FakeMuse has been designed, a single-player mobile game developed for Android smartphones, where players will play the role of an intern curator of a fictional archaeological museum to collect as many artefacts as possible as a consequence, expand the museum collection. The aim will be reached by understanding if the proposed objects are authentic or not. If players can do this, the artefacts will be added to the collection and exposed; in this way, the museum will also increase its economic income, named MusEuros. To facilitate the decision process, the players can spend the cultural coin of the game named Lauros to obtain some clues associated with the artefact. Lauros are obtained by playing with some minigames and buying particular short magazine articles (Fig. 2). The design of FakeMuse followed specific requirements. The target group selected for the game is young adults (19–24 age) to twenties and thirties (25–35 age) who do not have a specific background in humanities. The characteristics of our target users have been established, creating a set of personas as a reference during the design process. For what concerns the game's contents, it has been decided to use authentic artefacts to present to the players, and all articles and minigames contents are made by the archaeological members of the MemO Projects, using a web portal related to the remote application database. The players will obtain information on the artefacts collected, knowing the membership collections, the description, and the real museum where they are exhibited.

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[3] Written by Daniel Zilio.

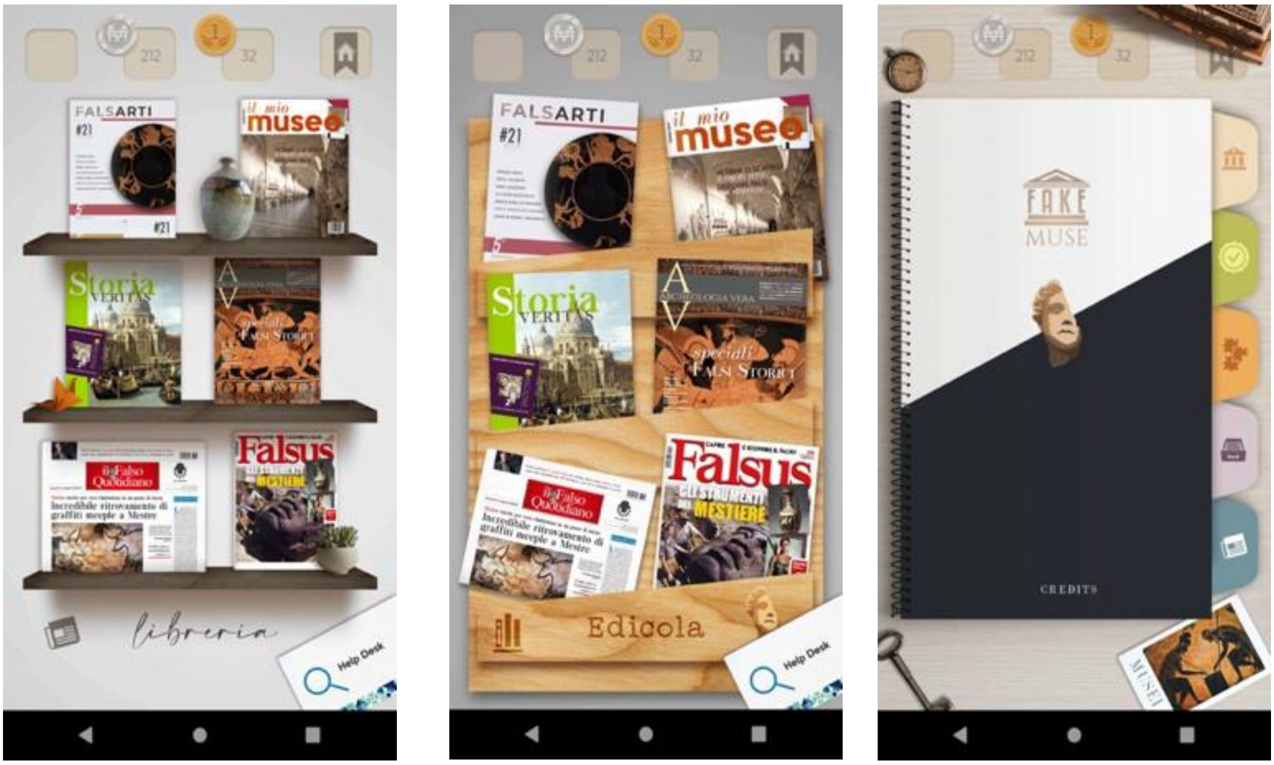

Fig. 2. Three examples of screens: The Home and the Newsstand with magazines (© D. Zilio)

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3D modelling of the castle Neu-Wildon

Applying UAV-based photogrammetry, terrestrial photogrammetry and terrestrial laser scanning – a comparative study

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Keywords: *Laser scanning—UAV—Photogrammetry—Virtual Reality—Neu-Wildon*

CHNT Reference: Bauer, P., Kaufmann, V., Sulzer, W., Lienhart, W., Mikl, T., and Seier, G. (2022). '3D modelling of the castle Neu-Wildon', in Börner, W., Rohland, H., Kral-Börner, C. and Karner, L. (eds.) *Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020.* Heidelberg: Propylaeum.
doi:10.11588/propylaeum.1045.c14507

Introduction

In 2020 renovation work and protective measures were carried out at the castle complex Neu-Wildon. During this work the whole site was not only scanned with a Leica RTC360 laser scanner, but also captured with a Nikon D800 digital camera for terrestrial photogrammetry and additionally surveyed applying UAV-based aerial photogrammetry using a quadrocopter DJI Phantom 4. The main aim of the survey was to document the remaining parts of the structure in every detail to provide a solid data foundation for scientific building research. On the basis of these datasets a 3D reconstruction of the castle has been attempted.

Control points

To accomplish a reasonable accuracy level with every reality capture technique the usage of control points is inevitable. Therefore, 19 ground marker plates and 250 wall markers have been measured from 17 setup points with a geodetic total station. The setup points have been adjusted with redundant measurements in a geodetic net to reach a position accuracy of 1–2 mm. These control points served as the geometric reference for all used surveying methods.

Geometrical deviation between the 3D results

49 laser scans have been taken with the Leica scanner RTC360 on site. According to the instrument's datasheet and proved by internal quality checks the scanner fulfils an accuracy of 1 mm + 10 ppm (e.g. 5.3 mm @ 40 m). The alignment of the scans was established with cloud to cloud approaches with a minimal overlap of 28% and stabilized by 17 equally distributed scanning targets (i.e. control points) on the setup points of the total station. The overall error at the target plates after

the adjustment was 4 mm and therefore provides a homogenous geometrical reference with an object accuracy of below one centimetre.

The internal camera of the DJI Phantom 4 acquired digital images with a frame size of 4000 × 3000 pixels. The pixel size of 1.56 µm relates to a ground resolution of 18 mm at a flying height of 43 m above ground. The images have also aligned and georeferenced with the ground markers using custom SFM software.

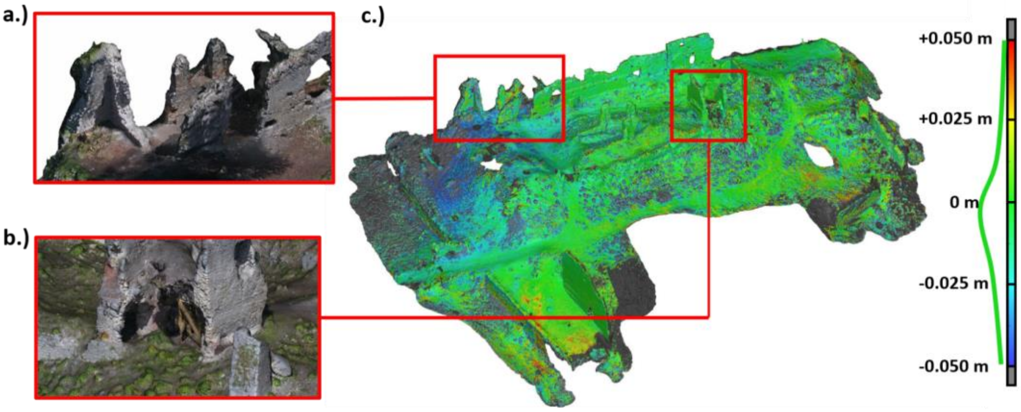

Fig. 1. Cloud2Mesh comparison between laser scan (cloud) and UAV (mesh) data with detail images of a) the northern living quarters and b) the kitchen

The Cloud (Scan) to Mesh (UAV) comparison in Figure 1c shows that 75% of all deviations are within ± 2.5 cm (histogram at the scale bar). The best results can be obtained from open ground without vegetation and from exposed walls. However, due to the limited coverage from above, narrow areas as seen in the northern living quarters (Fig. 1a) or covered areas like the kitchens storage room (Fig. 1b) have vast errors where the meshing algorithm has smoothed and auto filled these areas. The most prominent parts of the structure have been captured with 1088 images using the Nikon D800 digital camera. The images have also been aligned and georeferenced with the wall markers using the same SFM software. The comparison of the laser scan point cloud with the model derived from terrestrial photogrammetry shows a high congruence (few millimetres) in the central area where nearly orthogonal viewing directions were possible. In the palas, where the dip angles were steeper, due to space limitations, a systematic deviation occurs of up to two centimetres at the top region of the wall.

Level of detail

Figure 2 shows a comparison between all three observation methods. Therefore, cutting planes have been calculated through all 3D models and displayed in Figure 2d.

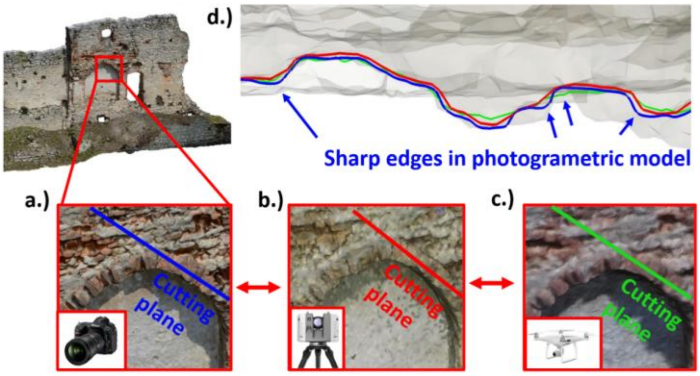

Fig. 2. Comparision between the different observation methods a) SLR model b) TLS model c) UAV model d) by using geometric cutting lines through the obtained 3D models

Regarding the obtained UAV-based model in Figure 2c, single bricks can be hardly distinguished and due to the camera look direction from above many small 3D features, such as pole holes, shafts and small windows, are only represented as black spots in the texture. Therefore, it is not suitable for detailed investigations beyond obtaining a digital surface model.

The laser scan model in Figure 2b has a mean point distribution of 5mm on the object which leads to better resolution compared to the UAV but also single bricks are hard to be identified. Also for the adequate 3D representation of all feature parts without any obstruction a much higher number of scans would have been needed which would have increased the raw data enormously on the other hand. Terrestrial photogrammetry has the advantage that 3D features are covered from various angles, providing more complete models. In Figure 2a it can be seen that the camera resolution captures the different materials of the wall and has sharp corners between adjacent objects. Only here the required level of detail for scientific building research is met.

3D modelling

According to the visible construction features and on the basis of historic paintings and plans (as seen in Figure 3a & 3b) a reconstruction of the initial state of the castle at the end of the 16th century has been attempted. The large scale geometrical features, such as wall lines, wall thickness and heights, have been extracted from the laser scan model. The small scale features, such as windows, pole holes and floor levels, have been modelled according to the highly detailed Nikon camera-based model. Due to the lack of large scale archaeological excavations a major part of the 3D model had to be extrapolated with logical considerations based on geometrical and topological necessities. For sustaining these extrapolations, the model has been accessed with Virtual Reality gear during the process, as seen in Figure 3d, to check the feasibility of floors, windows and passage ways from a visitor’s point of view.

Therefore, the 3D model in Figure 3c describes a plausible castle complex which is within the tolerance of the remaining structure and the available historic sources and may inspire further excavations for testing these working hypotheses.

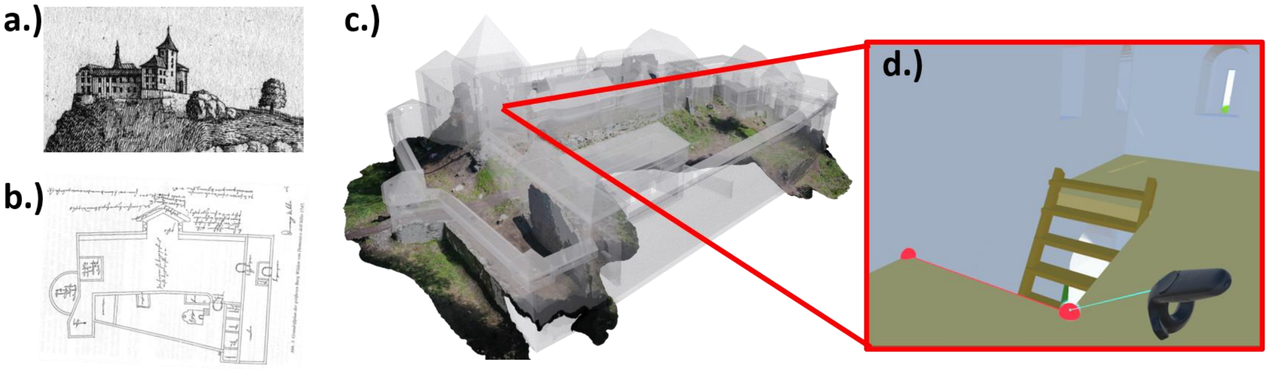

Fig. 3. View of the c) reconstructed 3D model according to a) a Copperplate by Vischer and b) a Plan of Domenico de U'Allio and d) a VR View while taking in-scene measurements

Result of the project

For the first time the whole castle complex has been captured in 3D and the remaining (visible) structures have been documented. The datasets have been shared with the castle owner and are accessible to other institutions for further building research.

The obtained 3D reconstruction describes the current state of the building research and may serve as basis for further reconstruction work. While creating this 3D model, areas have been revealed which need more attention in future research and excavation activities such as the area in front of the palas and the main gate with its surrounding buildings.

Lessons learned

This study has shown that:

- the UAV-based survey covers a wide area with a reasonable accuracy of a few centimetres for open areas. However, the UAV based model suffers from vast errors in obstructed and narrow areas of the historic building complex and was not suitable for further research.
- terrestrial photogrammetry can provide a highly detailed model, although geometrical insufficiencies in narrow spaces can be expected due to steep camera angles.
- terrestrial laser scanning delivers a consistent geometrical 3D model with a reasonable level of detail for geodetic monitoring but is not suitable for the representation of historic brickwork. In order to achieve high geometrical accuracy and the right level of detail at the same time, a combination of terrestrial laser scanning and terrestrial photogrammetry has to be used for the optimal result.
- Virtual Reality Gear is suitable for making design decisions during virtual 3D reconstruction.

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Virtual reconstruction for a physical restoration: a virtuous approach

The case of a Roman mosaic damaged by World War II bombings

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Keywords: *Mosaic—Ruin—Virtual Reconstruction—Photogrammetry—Restoration*

CHNT Reference: Somigli, L., Palla, A., and Toso, F. (2022). 'Virtual reconstruction for a physical restoration: a virtuos approach. The case of a Roman mosaic damaged by World War II bombings', in Börner, W., Rohland, H., Kral-Börner, C. and Karner, L. (eds.) *Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020.* Heidelberg: Propylaeum.
doi:10.11588/propylaeum.1045.c14508

The bombed mosaic from the former Fabbricotti collection at the Museo del Castello San Giorgio in La Spezia

The conservation treatment carried out on the fragments of a Roman mosaic from ancient Luni, now housed in the Archaeological Museum of La Spezia (Museo del Castello San Giorgio), Italy, raised several methodological issues and required a somewhat innovative approach.[1] The mosaic is referred to as Mosaic n. 2 of the "Fabbricotti collection"—after the name of one of its previous owners—and it was originally a polychrome tessellated pavement measuring about 2,43 × 2,53 m. It was broken into hundreds of fragments and partially destroyed in the wake of the heavy bombings that deteriorated its former conservation premise during World War II (Alessi et al., 2020). In its current state, it can be considered as a ruin—a very significant condition in view of the theoretical approach to its conservation. The first part of the intervention aimed at identifying the fragments belonging to this mosaic among those kept in storage at the museum, in order to attempt a restoration of its surviving pieces. The only representation of the undamaged mosaic was a historical photograph dating back to the 1930s (Fig. 1). Although no tools were specifically developed to carry out the reconstruction (as a whole or in parts) automatically, several digital techniques and tools were used to support the conservators' work in the manual search for the reassembling of the fragments[2].

The digital approach to the restoration process

The intervention started out with a systematic analytical study and filing of the nearly 300 fragments taken from the museum storage. Then all the fragments were documented through a high-resolution

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[1] This intervention was carried out in the frame of a graduation degree project at the School of Higher Education of the Opificio delle Pietre Dure in Florence, supervised by Francesca Toso, Marco Ciatti, Anna Patera, Andrea Cagnini and Fabio Fratini, whom we gratefully acknowledge.

The digitization of the fragments was carried out thanks to the collaboration of the academic spinoff of the University of Florence "Laboratori Archeologici San Gallo", composed of a team of medievalist archaeologists including Lapo Somigli.

[2] Due to the purpose of the project and the intrinsic criticality of the case study, there were no conditions to develop tools that could automate the recomposition process (merely as an example, see Hernandez et al., 2019 and Riccio et al., 2015).

photographic survey to obtain a 3D model of each fragment and orthophotos of all the tessellated surfaces, through stereoscopic photogrammetry techniques and processing of structure from motion.[3] The aim of the survey was not merely to generate a digital copy of the fragments, but it was primarily intended to provide the operational means to implement a digital reconstruction of the mosaic. The first step took place in a 2D environment: the orthophotos were used to find the original position of each fragment. This was achieved by overlaying these images on a background representing the photograph of the mosaic prior to its deterioration (Fig. 2a). To obtain the most accurate result, the photograph was undistorted through photo straightening processes based on the mosaic's square frame and known dimensions.[4] This method allowed to determine the exact original position of 75 fragments, and to identify a suitable position for another 113 fragments. Subsequently, a 3D re-composition of the virtual models was undertaken, which ultimately provided a clear image of the actual material consistency of the mosaic's remaining entity, showing that it corresponds to about 40% of the original surface (Fig. 2b). It also showed that in this specific case it was possible to attempt an actual reconstruction of the surviving part of the artifact, thus allowing its future exhibition to the public.

Fig. 1. The undamaged Mosaic n. 2 of the former Fabbricotti collection in a historical photograph. Published in Fabbricotti, C. A. (1931). Alcuni cenni circa il Museo Lunense (privato) "Carlo Fabbricotti" in Carrara, typescript.

The physical reconstruction of the mosaic

The virtual phase was hence followed by a physical one, where the fragments were placed onto a new support reproducing the original shape and dimensions of the mosaic. Each fragment was backed with a small stand and fixed on the support using re-closable fasteners, to allow possible rearrangements of those whose position was not positively identified. In case new data become available, both the virtual and physical reconstructions can be updated by editing the 2D and 3D models of the mosaic and rearranging the actual fragments accordingly. The fragments were then

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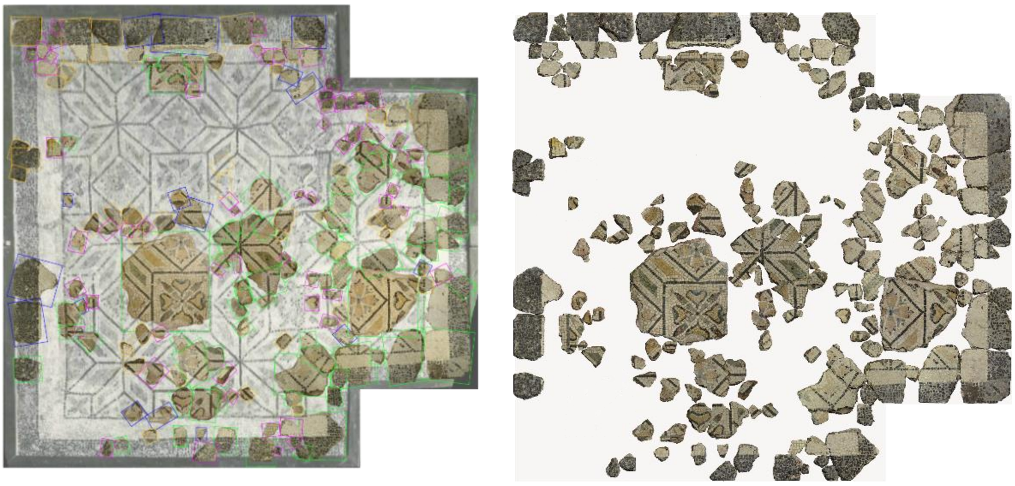
[3] The software used was Agisoft Metashape. Photos were shot with a Nikon D-7100, 24.1 megapixel DX-format CMOS sensor and Nikkor 18-105 f/3.5-5.6 VR lens. 3D models were exported as PLY files and JPG textures.

[4] The precariousness of the available data allowed to obtain an orthophoto with an error in the order of 2 cm, which was considered to be acceptable for the prefixed purpose.

associated with a representation of the missing surface, printed on an aluminum composite sheet (Fig. 3a), that fills the gaps and recreates a visual context without properly reintegrating the original artefact. This exhibition device was entirely designed using the 3D model of the virtual reconstruction of the mosaic (Fig. 3b).[5]



a *b*

Fig. 2. The digital reconstruction of the mosaic: a) 2D reconstruction with the orthophotos of the fragments overlaid on the straightened historical photograph of the undamaged mosaic; b) 3D rendering of the mosaic's surviving fragments. © Museo del Castello San Giorgio.

Conclusion

During this intervention the photogrammetric data proved to be an essential tool not only in the preliminary digital phase, but in the following parts of the restoration as well, providing means to present the mosaic efficiently in a museum display without concealing its current fragmentary state. In that sense, the digital modeling allowed to give a physical context back to the fragments by re-establishing their legibility. Moreover, having designed a stable yet unclosed solution for the setting of the actual fragments on their new support, leaving the possibility for further rearrangements open, the digital reconstruction may still play an active role in the intervention in spite of its apparently auxiliary function. Although this experimental study on the use of digital tools in the conservation of cultural heritage originated from the specific need to physically restore the surviving fragments of the Mosaic n. 2, the adopted procedures can find broader applications in the development of new methodologies in the restoration of fragmentary artefacts. At present, once the physical phase of the reconstruction is completed, various research perspectives remain open in two main directions: on one hand in the use of digital tools for the physical restoration of fragmentary artefacts and on the other hand in the development of applications that can enrich the fruition of the artefacts in museums. As to the former, possible developments include programming tools that at least partially automate the repositioning process, which could be achieved through the recognition of the decorative features or by detecting possible matches in the break surfaces between the fragments. As regards the second area of research, prospective ideas involve the development of multimedia or interactive contents and devices

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[5] The 3D virtual reconstruction of the mosaic and the design of the display device were carried out with the collaboration of Mattia Mercante, using the softwares Pixologic ZBrush and Autodesk 3D Studio Max.

as edutainment experiences to enrich the museum display of the mosaic.[6] In particular, the virtual models (textured meshes of all the fragments on an 1:1 scale, already correctly placed in space) could be used to design an animation replicating the repositioning process of the fragments. For instance, the animation could start with a view of the fragments stored in boxes progressively “brought to life” and positioned on the empty frame of the mosaic.


a b

Fig. 3. Details of the physical reconstruction of the mosaic showing a) the fragments and the aluminum sheet displaying the missing surface, b) the set up in progress. © Museo del Castello San Giorgio.

This product, accompanied by detailed texts, pictures and videos explaining the various phases and showing the full process of the conservation work, could facilitate the viewers’ understanding of the restoration. Another potential idea involves the creation of an interactive app with which the visitor can try his hand at recognizing correct positions of the fragments, just like in a puzzle, starting from a two-dimensional background on which the decorative motifs of the mosaic are traced. The aim would be to make visitors understand both the technical and interpretative issues ad-dressed during the conservation work and therefore to enhance the scientific and methodological criteria that lead towards/to the reconstruction. Products of this type could be useful in improving the fruition of the museum exhibition by several levels of visitors (children, adults and specialists), and could also allow to develop the engagement of the public through the online presence of the museum (replicating the systems on web-based platforms), now more than ever encouraged by the pandemic situation of the recent months.

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[6] This area of research is encouraged also by Donatella Alessi, Curator of the Museo del Castello San Giorgio, whose contribution we acknowledge.

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Collection of forts and defensive structures at the time of the Grand Duchy

Research and historical-architectural interpretation of lost landscapes and territories

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Keywords: *Digital Survey—Giorgio Vasari—Fresco—Landscape Archaeology—Digital Reconstruction*

CHNT Reference: Emilio, G., Verdiani, G., and Della Monaca, G. (2022). 'Collection of forts and defensive structures at the time of the Grand Duchy: research and historical-architectural interpretation of lost landscapes and territories', in Börner, W., Rohland, H., Kral-Börner, C. and Karner, L. (eds.) *Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020.* Heidelberg: Propylaeum.
doi:10.11588/propylaeum.1045.c14509

Introduction

This research aims to develop a methodology to replicate digital 3D models of architectures, structures, and military forts painted in past pictorial works. A procedure of interest, while almost all these structures are transformed, in whole or in parts, in the modern territorial and urban fabric.

The main subject will focus on *Palazzo Vecchio* in Florence and the great frescos of the wars won by the Grand Duke of Tuscany, Cosimo I, realized in the "Hall of the 500" under the guidance of Giorgio Vasari, celebrating the Florentine achievements.

The reconstruction of the painted structures started with a match between the texts and archival sources, the digital survey of the Palace, the studying of the Hall, and the relationship between the topic shown in the painting and its ambience.

The main starting questions were: How to efficiently rebuild a 3D object from a 2D view? How to read the pictorial choices related to their historical time frame? How and where to find the historic contents needed to correctly reconstruct these structures? Which sources are more valuable? How to discover the point of view chosen by the author?

Methodology and operations

This project is part of the digital survey of Palazzo Vecchio, commissioned by the city municipality to the Department of Architecture (DIDA), University of Florence. This digital survey was operated in 2019 using up to three 3D laser scanner units along three weeks of survey work, acquiring about 5500 unique scans.

Palazzo Vecchio dates to 1299 and its surface covers an entire district of the city. The survey intervention processed all the major spaces as well as all the secondary, even minimal, rooms, to create the first, fully digital 3D map of the whole building. In it, one of the main spaces is the Hall of the Five Hundred. Here there is a large space. It is located on the first floor and measures 54 × 23 × 18 meters. It was built by Simone del Pollaiolo, called Cronaca, and Francesco di Domenico and commissioned by Girolamo Savonarola (1495–1496). During the governance of the Great Duke Cosimo I, it was restored by Giorgio Vasari (1555–1572). All the transformations of the hall, together with the frescoes painted by Giorgio Vasari in the formerly "Sala Grande" (the great hall), took about 14 years to be completed.

In order to report the scenery in the paintings, Vasari sent his collaborators to the territories of the battles to sketch the landscape and then develop studies about the proper point of views to set the scenes. All these works were done interpreting the space out of the present geometric construction rules, and getting various "licenses" in favour of a more impressive and dynamic result.

Table 1. Classification of the frescos.

Cycle	Title	Date of realization	Date of the event	Position in the Hall	Authors
war with Pisa	*Assalto di Pisa* – Assault to Pisa	1568	1499	North-West	G. Vasari and collaborators
war with Pisa	Massimiliano d'Austria toglie l'assedio a Livorno – Maximilian I ends the siege in Livorno	1567	1496	Central-West	G. Vasari and collaborators
war with Pisa	*Sconfitta dei Pisani alla torre di San Vincenzo* – The Pisan army defeated at the St. Vincent Tower.	1569	1505	South-West	G. Vasari and collaborators
war with Siena	*Assalto al forte di Siena presso Porta Camollia* – Assault to the Siena fortress near the Camollia's gate.	1570	1554	North-East	G. Vasari and collaborators
war with Siena	*Presa di Porto Ercole* – The fall of Porto Ercole.	1570	1555	Central-East	G. Vasari and collaborators
war with Siena	*Rotta di Piero Strozzi a Scannagallo in Valdichiana* – Pietro Strozzi defeated in the Scannagallo battle, Valdichiana.	1571	1554	South-East	G. Vasari and collaborators

A specific digital survey intervention

The base obtained from the 3D LS survey operated in 2019 was integrated by a specific high-resolution photographic survey. The tools in use were: a DSLR NIKON D800E with 36.3 Megapixels resolution and two different lenses: a NIkkor AF 24–120mm F4 zoom and a Nikkor AF 70–300mm F4.5 zoom. The first lens permitted high-resolution shots of each painting in the context of the room. The second lens allowed detailed shots of the architecture painted in the background of the scene. All the shots were later processed to correct perspective distortions on the base of the 3D laser scanner survey. After the first analysis of the painting, a site-inspection was conducted in Porto Ercole, a small city located nearby Monte Argentario, southern Tuscany, one of the areas where the battles, painted by Vasari, took place. It was the first testing ground for this research.

Meet "The hold of Porto Ercole"

In Porto Ercole in 1555, the troops from France and Siena faced the Spanish-Medici forces in defence of the territories of the Republic of Siena. This event was depicted in several works. In *Palazzo Vecchio*, there are two paintings that narrate "la Presa di Porto Ercole": one is analysed in this case study, the other was created by Giovanni Stradano in 1572.

Table 2. The defensive structures depicted in the Fresco.

Fortifications	**Settlement timeline**	**Archival references**
La Rocca (readjustment)	1552–1553	Plan of the Fort found
Construction of forte avvoltoio	October 1552–May 1553	Missing plan
Construction of forte della Galera	April–May 1554	Missing plan, shape of the pentagonal fort
Construction of forte Stronco	October-November 1554	Missing plan, shape of the quadrangular fort
Construction of forte Guasparino	1555	Fort plan found, but uncertain
Construction of forte Sant'Ermo	March–April 1555	Fort plan found, but uncertain
Construction of forte Ercoletto	April–May 1555	Fort plan found
Construction of forte S.Ippolito	1555	Missing plan, simple bastion

In Vasari's Fresco, the two factions are seen facing each other. In the background the coastline between the sea and the land. Battleships, troops and camps settle around eight military forts. Small structures, located on promontories and strategic points, host few soldiers, ready to attack with artillery. The depicted forts were later replaced by two more advanced fortifications, which are still present in the area. From one of these, the *Forte Stella* may be identified as the point of view adopted by Vasari. From a first observation, comparing the painting with the photographs from the site, it may be noticed that Vasari had adapted the territory in order to fit it into the painting and had raised the horizon line to give more space to the scene and better show the forts, while the course of the coast is verisimilar.

Thanks to the contribution of the historian Gualtiero Della Monaca, it was possible to find the real position of the eight sixteenth-century forts and to realize models of their original form and structure. Della Monaca provided the plans (found in annexes to archival writings that he collected during his research), from which it was possible to reconstruct the fortifications.

Of the eight forts, four original plans have been found (although not all of them are fully confirmed) whereas four are missing and are only described in texts. Based on this information, the forts were digitally modeled in 3D and repositioned in the geographic map of Google Earth on the territory of Monte Argentario. The intention is to build a map with a well-defined degree of approximation for each model, in order to properly classify the level of knowledge achieved relative to all forts, while at the same time, to underline the transformation in the urban/natural landscape and the level of valorization (as a way of facts or as a potential) of the built heritage arrived in the present days from the late Renaissance scenario.

Fig. 1. *Outline of the fresco “The fall of Porto Ercole” and a sample of the processing.*

Short acknowledgements

The Digital Survey of Palazzo Vecchio was conducted inside the research “Vulnerabilità sismica di edifici strategici e rilevanti, storici e monumentali posti nel Comune di Firenze – Rilievo 3D Laser Scanner di Palazzo Vecchio”, on the base of an agreement between the Florentine Municipality and the Dipartimento di Architettura, University of Florence. General coordinator of the agreement: prof. Mario De Stefano, coordinator for the Digital Survey operations: prof. Giorgio Verdiani.

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Round Table:
Integrating Artificial Intelligence in Cultural Heritage sites’ audience research

Andi SMART | Cristina MOSCONI | Pikakshi MANCHANDA

Call

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Keywords: *Digital Technologies—Artificial Intelligence—Audience Research—Business Model Innovation—Economic Development—Site Management*

The implementation of digital technologies in cultural tourism is increasing at a rapid rate and becoming an essential tool for cultural, archaeological and heritage sites to increase appeal and attract more visitors. While the creative process of digital interpretations has often taken the spotlight, less attention has been paid to the underpinning analysis of management and economic structures providing all the visitors' data which makes the digital implementation successful. The informed use of AI approaches based on the analysis of visitors' data could represent an innovative way of seeking synergies between economic and technological aspects to broaden the tourist experience in a sustainable way. Such approaches aim to find an answer to questions like: who is the target audience of new digital experiences? What will such experiences offer them and will visitors' expectations be met? What are the best digital technologies to reach the target audience? And also, how can new digital experiences eventually increase the revenue stream? Answering these questions will provide new insights for Cultural Heritage (CH) sites and provide baseline intelligence for new innovative business models to emerge. The aim of this round table is to encourage contributions investigating the emerging adoption of AI technologies for conducting audience research and shaping existing business models aimed at the implementation of innovative digital solutions compatible with the organisational and economic characteristics of CH sites. In particular, contributions are sought that look at case-based approaches in the cultural heritage sector, which investigate the main issues faced, and opportunities encountered, when exploring the implementation of digital technologies.

Research on approaches for implementing changes to establish practices are encouraged.

Experiences of the implementation of digital interpretation, best practice approaches, tools and methodologies, are also welcomed.

AI Visitor

Tracking Pedestrian Trajectories for Machine Learning Applications in Machu Picchu, Cusco, Peru

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Abstract: Studying and managing pedestrian movement is essential for cultural heritage sites and public spaces. Much current software, such as evacuation simulators, typically uses ruled-based approaches and visualizes how people move. However, it is difficult for such software to provide critical simulations of visitors that wander through touristic sites. Solving this problem through a data-driven approach, this paper presents the data processing method for Machine Learning applications that simulates how human agents navigate space. This research aims to develop intelligent agents that emulate human pedestrians moving in response to their spatial environments, including architectural features (AF), which refer to spatial aspects of the environment, such as peculiar buildings that attract visitors. AI Visitor is a prototype that includes a pipeline of onsite data collection and the training of agents. This paper introduces the case study of the Machu Picchu citadel, built-in Peru during the 15th century by the Incas, attracting approximately 2000 visitors a day. The raw data was collected through extensive aerial video recordings from drones, providing 0.5 meters of data granularity. Tourists' trajectories were extracted through computer vision, and the AF were identified and scored. Next, two Machine Learning techniques were combined; Reinforcement Learning (RL) used the AF as input for training the agent, and Imitation Learning (IL) deployed human path trajectories as demonstrations for the agent. The combined model helps train complex behaviors of the agent efficiently from a relatively small group of datasets. As a result of applying the data processing method to areas of the Machu Picchu case, the preliminary result indicates the trained agents autonomously trace human trajectories data and move in search of architectural features. The potential use of such data-driven pedestrian modeling includes applications to circulation and facility design of the sites, capacity management of visitors, and administration of social distancing.

Keywords: *Pedestrian Simulation—Machine Learning—Video Tracking—Cultural Heritage Site*

CHNT Reference: Gonzalez, P. and Nagakura, T. (2022). 'AI Visitor. Tracking Pedestrian Trajectories for Machine Learning Applications in Machu Picchu, Cusco, Peru', in Börner, W., Rohland, H., Kral-Börner, C. and Karner, L. (eds.) *Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020.* Heidelberg: Propylaeum.
doi:10.11588/propylaeum.1045.c14511

Introduction

Contemporary pedestrian simulation tools generally deal with limited aspects of human behavior, such as emergency egress and traffic crossing. Most of these tools use procedural models such as rule-based ones. For instance, Agent-Based Models (ABM) enable the modeling of sophisticated crowd dynamics (Pedica and Vilhjálmsson, 2008). MassMotion is a procedural tool of ABM for egressing pedestrian simulations, among others[1]. While these tools are helpful in specific simulation contexts, they exclude more complex human behaviors. One relevant example is trajectory paths sidetracked to approach an interesting view or freely traversing space sightseeing on cultural heritage sites.

Including these exploratory behaviors in a simulation tool increases the accuracy of simulating humans in an everyday context and enables modeling deviations from expected trajectories. However, building such a tool requires new insight into how to retrieve and embed such human behaviors. The AI Visitor presented in this paper applies a Machine Learning model to exploratory pedestrian movement through heritage sites to simulate and predict the anticipated direction of people in real-time. This would be useful, for example, for designing a circulation path of visitors and managing the capacity of the venue with proper social distance.

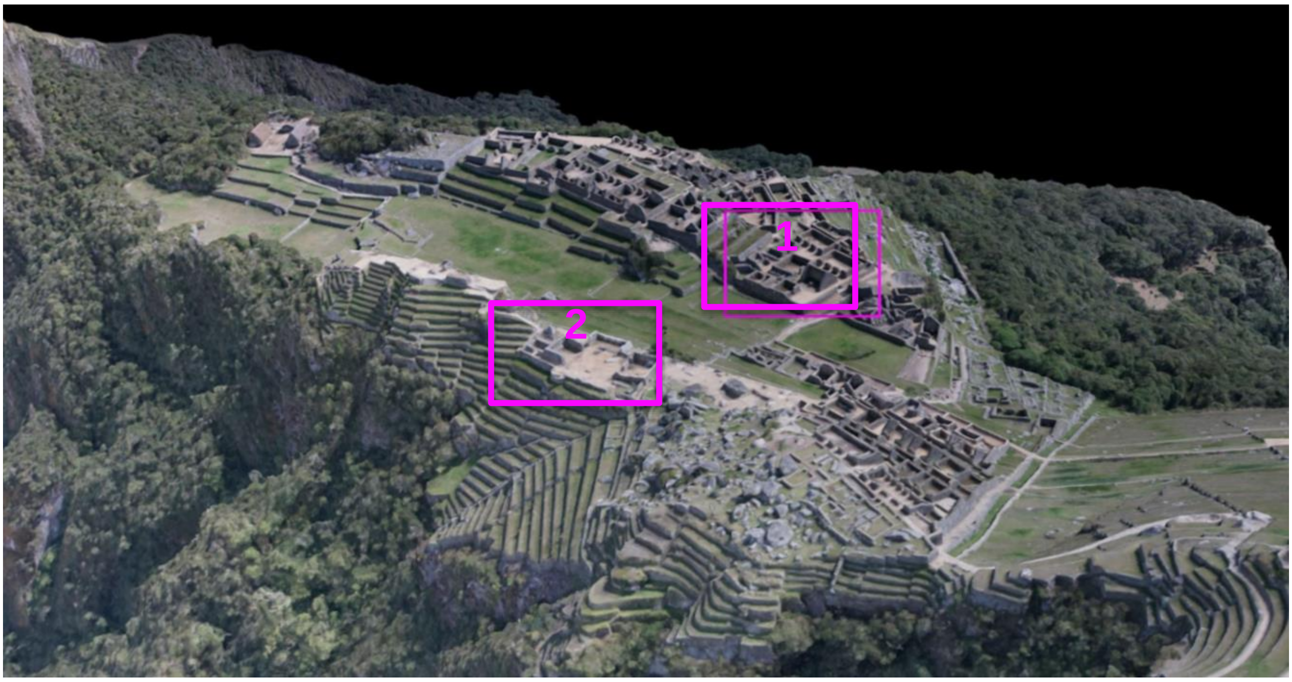

Fig. 1. A photogrammetric model of Machu Picchu (Model by Cesar Medina, 2018). The framed area with the number '1' is the "Two Mirror Temple." The framed site with the number '2' is the "Three Windows Temple." (Model by Cesar Medina, 2018).

AI Visitor's input and data processing pipeline includes onsite data collection, pre-processing, and the training of agents used for simulation. At the outset, a drone flying over the site is used to record the human visitor's movement in video and photograph the site's architectural conditions for 3D photogrammetrically modeling. The raw data then is pre-processed to harvest the human trajectories by tracking the recorded pedestrians through a computer vision software and the locations of architectural features identified and scored as visitor's attractions. The ML model then feeds on the pre-processed data and trains the agents in a simulated, digital site version. After training, agents can finally be tested by comparing their movement back to the recorded human visitors.

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[1] *Legion* is one of the most relevant software today, also rule-based, and destined to evaluate the emergency egress of airports and hospitals. Space Syntax is another ABM procedural tool that evaluates human sightlines and the accessibility of space as a graph. Space Syntax also has a module to analyze 'isovists,' the range of vision of a person or agent in a specific location, limited by the shape of the three-dimensional space. These tools are rule-based and depend on the modeler's knowledge, often harvested from experts, regarding the target behavior. Several researchers, such as Ng and Russell (2000), have questioned the limitations of relying on agent designers. They stated that they might have only a rough idea of optimizing a model to generate a desirable behavior.

The Machu Picchu citadel, located in Cusco, Peru, is the case study for this project (Fig. 1). This study is a significant and ideal cultural heritage testing ground with few roofs or coverings to impede observation. The selected areas are where free walking is permitted, and visitors wandering around the site are frequently observed alongside guided tourists. As seen in any specific cultural heritage site, the visitors in these areas actively contemplate various attractions, including peculiar scenes and monuments found during their traversing the space. Therefore, those areas are appropriate and advantageous sampling sites of human trajectory data and their motivating attractions as the source dataset for training the agents.

Fig. 2. Right: Two Mirror Temple area in Machu Picchu is captured into a photogrammetric model (Nagakura, 2018). Left: The pedestrians marked with yellow and blue boxes near the entries of the 'two mirrors' site are being tracked in the video recorded from a drone. © Authors.

Field Data Collection and Pre-processing

The field data were collected in Machu Picchu citadel, located on a steep mountain ridge, approximately 2500 meters above sea level. The data collection starts with video recording from a drone (DJI Mavic Pro) hovering at the same position at 50 to 70 meters in height. The flight time was approximately from 20 to 25 mins at a time, constrained by battery duration. The recordings of pedestrians at 4K resolution covered an area of 50 × 50 meters. The collected data comprises 30 mins of pedestrian movement at each of the five different regions of Machu Picchu; only two spots were analyzed, shown in Figure 1. At any moment, a typical video recording includes 9 to 10 'free walkers' and 60 to 80 people in groups with guides. The recorded data were processed using the OpenCV toolkit to extract visitors' trajectories. The data is discretized into steps every one second (Fig. 3).

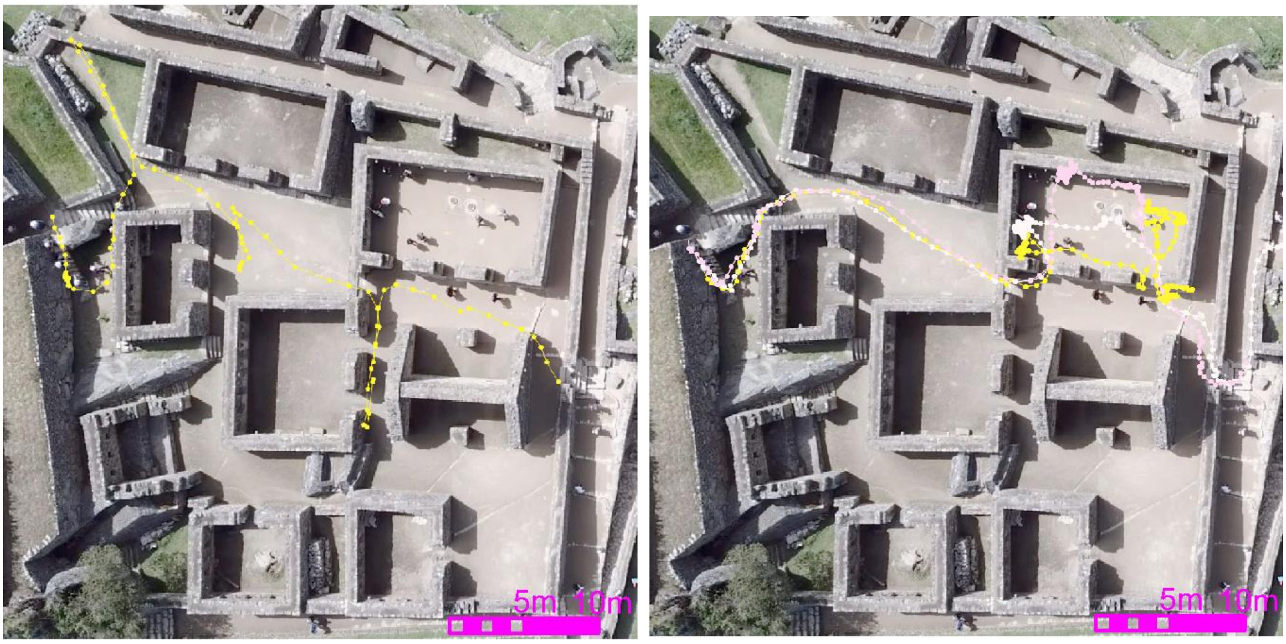

Fig. 3. The discretized route of a 'free walker' visitor (Left) and a guided group of visitors stop at the Two Mirror Temple that traces the path prescribed by the Machu Picchu park (Right). © Authors.

Forty free walkers were initially tracked from each of the two selected areas of the site (Fig. 1): "Two Mirrors Temple" (Figures 2 and 3) and "Three Windows Temple." Also, forty guided people in groups of 6 to 9 visitors from both areas were tracked. The walkers were classified into those two groups, free walkers and guided tourists, by applying a Bayesian model classifier called "Bishop" written and developed in Python by Julian Hara-Ettinger (2012). The classifier compares the extracted trajectories to the "most probable route" between two points, assigning a score to the main steps of the extracted trajectories. Next, the trajectories with the lowest scores are deemed unguided explorers and classified as 'free walkers.' This method filtered the explorer trajectories from all the rest, such as those of tourists in guided tours or workers moving on duty, in the dataset.

In addition to the video used for pedestrian tracking, thousands of photos were taken from the drone flying over the site. Using photogrammetric software, those photos were processed to generate the textured mesh model first. Using it as a reference then produced a simplified 3D model, appropriate for agent training sessions later in Machine Learning.

Further along with the data processing, a unique data label, the 'architectural features' (AF), is introduced to support the computation of the agent's interaction with the environment. AF is defined as 'appealing spatial configurations' that attract the trajectories of the visitors, often leading them to explore. Examples of AF are an exciting view such as one commanding the nearby mountains and another looking down on the excavation site from a high point; a building with unique formal or material conditions; its parts such as a pediment, a terrace, and a window; and a peculiar residual space such as a narrow corridor or a large stepped balcony. Particular objects of attractions are included in AF as well. For example, the 'Two Mirrors' in Machu Picchu are two small circular cavities containing reflective water located in the temple-like enclosure within the highlighted area in the left image of Figure 2. The AF analysis explains why people often deviate from the prescribed tourist paths towards specific locations.

Fig. 4. Two Mirror's temple, showing the scored architectural features (AF): 1. Terrace with a view towards the nearby mountains, 2. Two Mirrors (round pools on the ground), 3. Building with Rock, 4. Large Tiers, 5. Building with windows towards the main grass field, 6. Terrace towards the main grass field, 7. Building with a pediment structure without the roof. The bottom left image shows a heat map with the hotspots of the trajectories. The red circles represent the locations where the visitors spent more than 1.0 seconds, the orange circles represent the locations where the visitors spent more than 0.5 seconds and less than 1.0 seconds. The yellow circles represent the visitors' locations spent less than 0.5 seconds. The green areas are the traces of the paths. The steps are defined every 100 cm distance, approximately 1.0-second intervals—the images on the right show three AF locations. © Image by the authors and photos on the right column courtesy of Eytan Man.

Identifying the AF relies on three sources: the first source is the visitors' behaviors and the amount of time they pause at a location on their trajectories. A shared long pause is evaluated to indicate an attractive feature for visitors. The second source is the official map of Machu Picchu and the information given by the guides, signs, and other onsite authorities, which advises the visitors of the critical and famous locations of the site. Research collaborators with architectural design backgrounds identified additional potential attractions on the site. Figure 4 shows all the AF identified in the "Two Mirrors Temple" site. For example, the "Two Mirrors" is one of the well-known attractions in Machu Picchu and is placed on the official map distributed to all visitors at the main entrance gate into the citadel park. Its location and photo are numbered 2 in Figure 4. On the other hand, places like the one numbered 7 in Figure 4 are not introduced in the Machu Picchu map but are identified as unique architectural features because of their shapes and ruined conditions distinct from others nearby.

Another example is the location numbered 1, a terrace that many people are observed flocking to visit and lookout. In Figure 4, this terrace shows a red hotspot where many visitor trajectories pause. Although the official Machu Picchu map indicates nothing is there, it is a popular location for visitors because of the grand panoramic view towards the nearby mountains. According to the data in Figure 4, there are many such anonymous locations where many people are proven to pause and pay attention.

Each of the AF identified on the site is rated by a scoring system that measures the average time spent by the visitors at the respective location. The highest score is for the most popular site, including the “Two Mirrors,” and is equivalent to 7. The lowest score is for the visitors’ location spent the least time. The place numbered 5 in Figure 4, ‘the building with windows towards the main field,” got this score. In the next step of data processing, these scores are normalized and mapped to the reward system for the RL model, resulting in rewards in the range between 0 and 1.0.

Overall, the limitations of the Data Production for this research were: to collect human trajectory data only from a public space and exclusively from visitors of a tourist destination—the tourist site’s regulations highly constrained the behavior of those visitors. For example, they are allowed to stay for a determined amount of time, can only walk in one direction, and cannot wait for long periods in any location. Furthermore, the visitors are only middle-aged to older adults with good physical shape to endure physical activity. The data does not include people with challenged mobility. Finally, the data was collected during which the tourists visiting Machu Picchu travelled from the North Hemisphere. Therefore, this dissertation dataset was limited to the data collection conditions. Finally, the assumption is that this analysis only includes first-time visitors.

Machine Learning Process

This research is inscribed in modeling intelligent agents to simulate pedestrian behaviors. Agent-Based Models (ABM) is its typical rule-based modeling method, as previously mentioned, and verbal behaviors, such as walking the shortest path to leave a room in an emergency, are formalized into rules, embedded into the agents, and sequenced for simulation. However, how and why humans traverse the environment beyond deterministic paths is often not obvious. Identifying and describing a set of rules for modeling agents in ABM is not a trivial task even for experts. For instance, it is difficult to define rules for visitors exploring the cultural heritage sites, who often seem to move unpredictably by frequently deviating from their prescribed path to various locations, in such a context where machine learning methods augment well-established rule-based models.

The motivation of this paper is to present an alternative, data-driven method of agent development that applies Machine Learning. It computationally samples and deploys the likely patterns of human behavior from the field data containing varying degrees of noise and outliers instead of using the researchers’ well-defined expert knowledge or analysis. In Machine Learning terms, agent behaviors are modeled by extracting policies that map policies assigning probabilities to agent’s actions at a given state are initially derived from the recorded human trajectories and updated in the machine learning procedure. In the Machu Picchu project, the onsite human trajectory data and architectural representation of the site were combined to drive the Machine Learning process to train the agents, whose behavior is stipulated by evaluating what architectural elements of the environment prompt visitors' actions to wander and deviate from prescribed paths.

AI Visitor applies two Machine Learning techniques, Reinforcement Learning and Imitation Learning, combined to overcome the shortcomings of each. The idea of using Imitation Learning to complement Reinforcement Learning for training agents has been found in previous research projects such as the ones by Pfeiffer et al. (2018), Youssef et al. (2019) and Juliani et al. (2020). Imitation learning generally helps train the agents efficiently with a relatively small training dataset used as demonstrations. Still, the trained agents often can only replicate the behavior 'taught' by such expert demonstrations. The challenge is to surpass such a limitation by combining this method with another traditional Reinforcement Learning, that uses a more generic but time-consuming reward-driven system for learning.

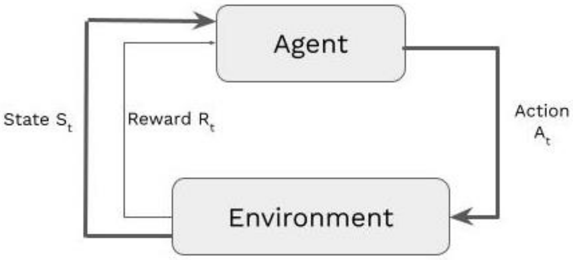

Fig.5 Basic structure of a Markov Decision Process (MDP) for Reinforcement Learning Agents. Adapted from Sutton and Barto (2018).

Reinforcement Learning (RL) is a method used to program intelligent agents to make valid sequences of decisions/actions. The structure of this agent model consists of state, actions, rewards, and policy (Fig. 5). The state corresponds to the current position of the visitor agent, and the action is its step-by-step movement. The reward is the cumulative amount of stimulus that the visitor agent collects from the environment, for instance, when an attraction is found on the site. The policy is a strategy for finding the rewards developed by the agent after training. The policy guides the agent about what action it should take in the next step which way to move or pause next. As the RL training sessions continue, the agent maps its training experience into a policy described in a probabilistic format. And as the policy develops, it maps agents' states to actions, so the visitor agents take advantage of the policy in deciding their next move.

In detail, the RL in AI Visitor lets an agent collect a reward when it encounters an instance of Architectural Features (AF). In the current implementation, the pre-processing stage before the Machine Learning training sessions identifies all the AF instances on the site. It adds each AF instance a score quantified from the ground data. As previously described, this score derives from the average time visitors spend at each AF location and establishes the rated rewards in the RL environment. During the training, the agent then maximizes the prize by visiting the AF locations, with each defined as a bounding box of 3 × 3 × 3 meters for the efficiency of RL computation. However, this bounding box can represent an attraction physically found beyond its location, such as a distant mountain view that a visitor can command from that location. When the agent approaches an AF instance, the collision detection is activated, and a reward is obtained.

The other Machine Learning technique used is Imitation Learning (IL), in which the agent emulates the ‘experiences of others by using them as the training input for learning. In AI Visitor, the experience of others is the experience of human visitors exploring the site and signified by the trajectories recorded in the field. Using these human movements as demonstrations, the agent learns which way to move or pause. In other words, the expert demonstrations are trajectories, with each instance of them represented in the form of: $\mathrm{t}_i = (s0, \mathrm{a}1, \mathrm{a}2, \mathrm{a}3, \ldots)$

The first term is the original state; a sequence of actions is taken during runtime. Only the data from the free walkers were used for Imitation Learning in the Machu Picchu project. The tourists in guided groups are excluded.

The Imitation Learning process assumes policies extracted from the experience of human visitors are appropriate for training agents. Therefore, if it is used for training a game competitor, the training dataset would require a careful selection to include only good demonstrations provided by solid players. For AI Visitor, there are no better or worse tourists to play the role of demonstrators. But identifying free walkers from guided tourists and others such as onsite workers is essential, and this classification method was discussed earlier in this paper. The Imitation Learning model works efficiently with a relatively small dataset once appropriately selected. At the same time, the Reinforcement Learning process often requires very intensive training cycles to achieve a similar result. The agent in the Imitation Learning process possibly learns and traces the demonstrations, including the nuanced behaviors human tourists make. However, because AI Visitor’s Imitation Learning process only considers the sequence of expert actions without explicitly utilizing the AF in the environment, it alone does not train the agent to properly behave in a situation much different from the demonstrated cases. The more robust, time-consuming Reinforcement Learning process using AF for rewards complements this problem in AI Visitor.

The training process in AI Visitor applies Reinforcement Learning and Imitation Learning simultaneously and is conducted in a simulated digital environment. In the Machu Picchu project, a simplified 3D model was reconstructed from the photogrammetric capture of the site first. The agent in the training software was forced to move on the recorded human trajectories. At the same time, it is presented with the isovist (i.e., the steering view around the agent’s head) of the reconstructed model (Fig. 6). At any location, the isovist commands the spatial configuration of the site from the vantage of the agent, with indications of all the architectural features (AF) in it. Through this training, the agent learns how to decide its movement in response to the surrounding spatial environments, including AF.

The ML model of AI Visitor was implemented using the Unity 3D ML-Agents Toolkit (Juliani et al., 2020). This toolkit implements ML on the widely used game engine software and generates intelligent agents. The ML process is defined as “model-free,” using only the experience extracted from the training data to achieve the optimal behavior of the agent. The Toolkit includes Proximal Policy Optimization (PPO) that optimizes the policy during the training sessions. The setup of the action space consists of 4 actions, forward, backward, rotate left and right. There are two types of rewards: a) Discrete rewards from following the demonstrations accurately, and b) AF rewards at specific locations, with a penalty of -0.001 at each training update, discounting from the cumulative reward if the agent is not changing location. Overall, the learning rate of the agent improved significantly when RL and IL were combined, as expected from previous work and the toolkit documentation.

Fig. 6. Machu Picchu digital model reconstructed from aerial captures and used as the simulated environment for Reinforcement Learning. Right: A plan view of the model shows the agent's visitors (red dots) exploring the site with indications of their isovists (yellow lines). Left: Example views correspond to the isovists at two locations. © Authors.

Preliminary Result and Future Applications

The trained agent in the Machu Picchu project has been tested by putting it back to the Two Mirror Temple model, where the field data was sampled from the human visitors. Its behavior was validated when its movement was observed compared to the human trajectories (the ground truth) in the source training set. This result indicates a strong potential of the proposed training method as a means of adequately embedding human explorers' behaviors on cultural heritage sites and the use of such an agent for effectively simulating how people deviate from predetermined routes.

The main contribution of this paper is the framework for developing a new pedestrian simulation tool for cultural heritage sites that uses architectural features as the motivation for visitors' exploratory movements and applies a Machine Learning method to train the intelligent agents for simulation. It described the methods for field data collection, extraction and classification of human trajectories, identification, and scoring of the architectural features, and applying the combined Imitation Learning and Reinforcement Learning model. Using these methods in the case of the Two Mirror Temple area in Machu Picchu, the trained agent was produced from a dataset of human trajectories and architectural features of the site.

The critical future step for this research is to test how the agent trained through the field data extracted from the Two Mirror Temple area moves when it is placed on other resembling areas of Machu Picchu. The evaluation should be made by comparing the simulated behavior of the agents to that of the human visitors recorded on those sites. If they are reasonably similar, pedestrian simulations created by the agents elsewhere would likewise be trusted. The measurement of similarity includes how the agent deviates from the prescribed paths and the locations and durations of the pause, indicating its reaction to architectural features.

The Machine Learning method described in this paper intends to make the agents replicate the behaviors extracted from the human visitors included in the training set. The factors for the optimization of the agent have the number of the sampled trajectories and the selection of one or more areas for recording the human trajectories and architectural features in them. While many portions around the center of Machu Picchu citadel include architectural formation analogous to the Two Mirror Temple area, other nearby spatial environments have long stairs, large stepped terraces, or open fields not found in the Two Mirror Temple area. The agent probably would need more training sets from those areas to simulate visitors of Machu Picchu in a comprehensive scope.

As for the architectural features, representations in Building Information Modeling (BIM) will be considered in the future development to move away from the manual process of AF identification described earlier in this paper. Suppose the target cultural heritage site model is available in BIM format. In that case, it is described as a composition of architectural elements classified by the types such as walls, floors, stairs, trees, terraces, and various subtypes of these. Computational tools for discretizing the mesh model from 3D scanning into a BIM model representation are emerging (Braun and Borrmann, 2019). The architectural features for AI Visitor can be prepared by systematically extracting relevant architectural elements in BIM data and interpreting them for features meaningful to visitors of the cultural heritage sites.

The current AI Visitor prototype is built around the Machu Picchu case study to prototype visitor agents there. Once this data-driven foundation is coupled with a good interface for applying data from any cultural heritage site, valuable tools for specific simulation purposes such as circulation and facility planning, capacity management, and social distancing administration can be developed to study, design, and manage the site efficiently.

Acknowledgments

A part of the fieldwork included in this paper was derived from the Cusco and Machu Picchu expeditions funded by the MISTI MIT-Peru program directed by Eduardo Rivera and conducted in collaboration with UNSAAC, the Cusco Culture Directorate of Peru. The authors thank Director Cesar Medina, Prof. Rene Navarro, and Prof. Wilbert Salazar for all the support provided during the fieldwork sessions and the MIT students who participated in the operation. Part of the field data was processed by Kimberly McPherson, MIT Undergraduate researcher, in 2020. Special thanks to Dr. Daniel Tsai for his valuable comments and assistance.

Funding

Please provide information if and by which institutions the research was funded. If applicable, provide the grant number of the funding agency.

Conflict of Interests Disclosure

Please disclose any financial or personal relationships with other individuals or organisations, such as sponsors, that could make your work appear biased or influenced.

Author Contributions

The authors contributed equally to the research presented in the paper.

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Round Table:
HERITAGE BIM

Process Optimization within Digitization Strategies

Claudiu SILVESTRU | Piotr KUROCZYŃSKI

Call

Claudiu SILVESTRU, hochform. Architekten ZT GmbH, Austria
Piotr KUROCZYŃSKI, Hochschule Mainz – University of Applied Sciences, Germany

Keywords: *Bim—Digitization—Process—Optimization*

Description of the round table: While dealing with digitization strategies it is impossible not to cross BIM. Regardless if in the public or private sector Building Information Modelling becomes increasingly the state-of-the-art technology for the creation, management and documentation of the building stock. The strengths of BIM rely among other on standardisation – from the definition of building parts to processes, if something can be made more efficient through recurrence, BIM is the tool to optimize it with. Nevertheless, the complexity of existing buildings with their irregular geometries, different phases of construction and a multitude of unknown aspects of the state of the fabric determine a specific approach towards BIM.

Scope of the round table: The standardization which makes BIM so appealing to large scale new building projects becomes difficult to achieve when dealing with cultural heritage. In this context both the scientific community and the AEC industry experiment with using BIM on existing buildings. At the same time public authorities demand increasingly to apply BIM also within conversion projects. Quite often the focus and goals of these three key actors are incoherent and drift apart. This round table aims to discuss the opportunities, strengths, and challenges of Heritage BIM as part of digitization strategies. The round table will include impulse papers addressing Heritage BIM in the digitization process from the point of view of public authorities, research and building practice. The objective is to identify and formulate key research questions on facilitating and improving the use of Heritage BIM within joint digitization strategies.

Manipulation of Archaeological Data as spatial Data and the Role of BIM and GIS

An overview from HS2 Phase 1, UK.

Fred Farshid ARYANKHESAL, HS2 Ltd, The UK

Keywords: *GIS—BIM—Spatial Data—HS2—Archaeology*

CHNT Reference: Aryankhesal, F. F. (2022). ‘Manipulation of Archaeological Data as spatial Data and the Role of BIM and GIS: an overview from HS2 Phase 1, UK’, in Börner, W., Rohland, H., Kral-Börner, C. and Karner, L. (eds.) *Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020*. Heidelberg: Propylaeum.
doi:10.11588/propylaeum.1045.c14513

Conserving our cultural heritage and historic environment as a legacy from the past for the next generations is an accepted value in sustainable approach to development. Such a vision has made archaeology research an integral part of the development process in the UK (Department for Business, Innovation & Skills, 2012). High Speed Two (HS2) Phase 1, is a new highspeed railway linking up London and the Midlands, which is comprised of the largest single archaeology programme ever undertaken in the UK. This paper will explain the role of GIS and BIM in manipulating archaeological spatial data in different lifecycles of this project.

Since 1960s revolutionary use of information and communication technology (ICT) for generating and processing information in surveys and studies has dramatically developed the role of digital data and computerisation in geography. Inevitably, this was borrowed in archaeological data manipulation, as well (Greene and Moore, 2010). Another aspect of any archaeological data is its association with location. Archaeology is among the fields in which “Place matters”. Without location, any archaeological data are devoid of identity (Fig. 1). Geographical location is an integral part of archaeological surveys. Like any spatial data such as census data and land use data, archaeological data is captured across geographic space, and is joined with geometrical shapes, such as historic buildings, test pits, trial trenches, intervention areas, etc. in a specific location with certain geographical coordinate system.

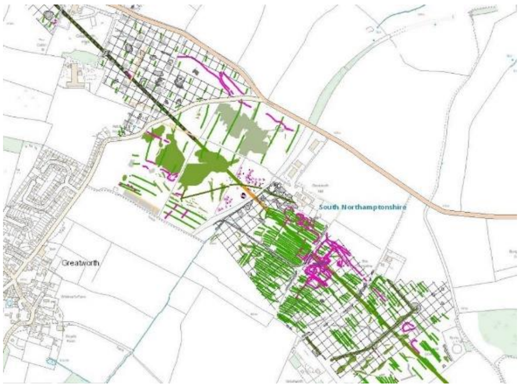

Fig. 1. Polygons and Lines GIS layers to represent a part of Interpretation of Geophysical Survey Results in Northamptonshire, HS2 Phase One, an example of visualisation of archaeological spatial data (© HS2 Ltd).

Processing of spatial data cannot be carried out without Geographic Information Systems (GIS). GIS is the science and art of systematic use of ICT. Archaeological data as geospatial data is captured/gathered from the features, existing or planned in the study area, in different GIS data layers. Various pieces of software and hardware such as sensors, cameras, drones, scanners, monitors, software packages, tools, printers, servers, video projectors, etc., systematically work together for capturing, gathering, cleaning, analysing, visualising/mapping, and delivery of Archaeological GIS data in different stages of archaeological surveys, including fieldwork, excavation, and post-excavation analysis (Green and Moor, 2010).

Where archaeological research is a part of a construction project, Building Information Modelling (BIM) can also be a valuable opportunity. BIM is a relatively new process for creating and managing information on construction projects across the project lifecycle, including design, construction, and operational stages (Department for Business, Innovation & Skills, 2012). BIM enables us to record and capture all archaeological assets, their hierarchy, and their interrelationship, alongside other construction elements.

Recorded and archiving archaeological assets in HS2 Phase 1 project provides us with a good example of using BIM and GIS in archaeological surveys (HS2 Ltd., 2017). As a subsystem of HS2's BIM, Historic Environment Research and Delivery Strategy (HERDS) has been established. Through HERDS strategy and help of GIS, a hierarchy of archaeological assets has been designed, which connects archaeological spatial data together, based on their interrelationship and their respective non-spatial supporting documents. For each archaeological asset a unique asset ID (UAID) has been designated in the system, and with using GIS, the location and geometry of assets have been recorded, and joined to their respective attribute table.

HS2 archaeological assets hierarchy comprises of five primary classes of assets. First, Location Specific Written Scheme of Investigation (LS-WSI) as areas of land that will largely be defined to meet construction needs, represented with polygon GIS layers; Second, Project Plans (PPs), as areas with specific packages of archaeological activities in order to achieve certain objectives of investigation, e.g. a series of geophysical survey, a building recording survey, archaeological excavation etc., which are all carried out in a certain piece of land, which its boundary is represented with polygon feature classes; In third level, there are Written Scheme of Investigation Interventions (WSI-Interventions), as the extents of single archaeological activities (e.g. a borehole survey, an individual trial trench), which again their boundary is recorded as polygon feature classes; Forth, Archaeological Features, as human-made non-portable elements with certain period, which their location and geometry are recorded as polygon GIS features. For example, an intervention area with trial trenching activity type, may uncover features such as post holes or ditches; Finally, Archaeological Objects e.g. hand axes, coins or brooches, found during archaeological investigations, which their location is represented with point GIS layers (Fig. 2).

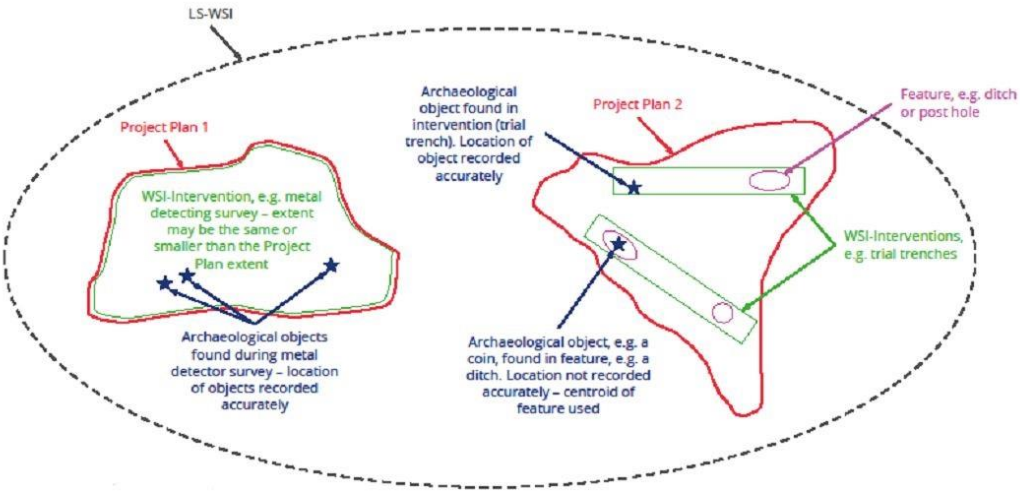

Fig. 2. HS2 HERDS spatial data hierarchy (© HS2 Ltd).

Such an efficient, transparent and readable data structure provides a lasting and valuable legacy for the lifecycle of the project. Also, an efficient integrated workflow has been created between contractors and their supply chain, HS2's Historic Environment team, and HS2 stakeholders, who benefit from those archaeological data in different lifecycles of archaeological spatial data, including data capturing, data cleaning and management, data analysis, data visualisation and data delivery (Fig. 3).

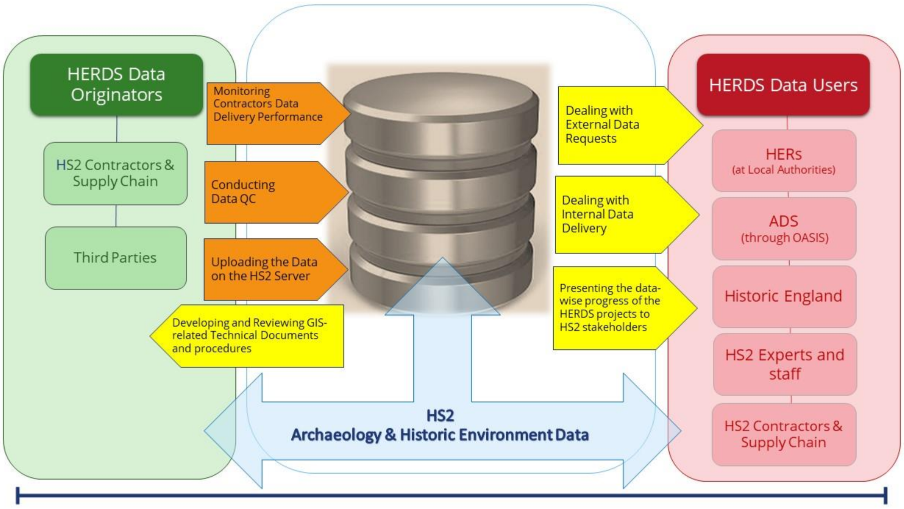

Fig. 3. HS2 Archaeological data lifecycle based on their Historic Environment Research and Delivery Strategy (© Author)

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Best Poster Award

Creating the Virtual Exhibition “They Shared their Destiny. The Women and the Cossack’s Tragedy in Lienz 1945” with FOSS

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Gerald HIEBEL, University of Innsbruck – Institute for Archaeologies, Austria
Philipp LEHAR, Museum Wattens, Austria
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Abstract: On the 75th anniversary of the Cossack tragedy in Lienz (province of Tyrol, Austria), an exhibition focusing on the fate of the Cossack women was planned to be hosted in the local Dolomite Bank. The role and destiny of women during the Cossack tragedy has remained untold until now, in contrast to the men’s viewpoint. The exhibition wants to tell the stories of different women to enlighten their fate. However, due to the strict regulations imposed by the Austrian government in the course of the Covid-19 crisis in spring 2020, it had to be realized in a virtual venue within short time. This report is structured the following way: After a brief introduction to the events that led to the Cossack’s tragedy, the article explains how the virtual exhibition was realized using exclusively open-source software and how the virtual exhibition now presents itself to visitors. For the 3D reconstruction of the exhibition room Blender was chosen. In order to make a virtual tour with the framework Marzipano, 360pictures were rendered from Blender. The final design and interactivity was then implemented in the three main script-languages for websites html, javascripts and css. Finally, a conclusion is drawn pointing out the advantages or disadvantages of the chosen methods.

Keywords: *VR—Virtual Exhibition—360° Pictures—Cossacks—Women’s perspective*

CHNT Reference: Danthine, B., Hiebel, G., Lehar, Ph., and Stadler, H. (2022). ‘Creating the Virtual Exhibition “They Shared their Destiny. The Women and the Cossack’s Tragedy in Lienz 1945”’ with FOSS’, in Börner, W., Rohland, H., Kral-Börner, C. and Karner, L. (eds.) *Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020.* Heidelberg: Propylaeum.
doi:10.11588/propylaeum.1045.c14514

Part 1: The Events that led to the Cossack’s Tragedy and the Exhibition

Historical Background

Over the centuries, the Cossacks turned from outlaws, pirates and robbers into loyal servants of the Tsars and played a central role in the process of expansion of the Russian Empire. During the Russian Civil War Cossacks fought on both sides (the communistic “Red Army” and the diverse groups besides the “White Army”). After its end, thousands emigrated amongst other countries to Yugoslavia, France and Germany while maintaining their Cossack identity. During World War II, some Cossacks and Caucasians volunteered to fight with the Germans against the Soviet Union for various reasons.

With the withdrawal of the Germans many Cossacks and Caucasians were forced to retreat with their families. Later, they fought in Yugoslavia and Italy, where the Germans promised them a new homeland. At the end of war, they feared being handed over to the Soviet Union, should they surrender to the Italian and Yugoslav partisans. Therefore, the Cossack and Caucasian troops together with their families marched north to the Drau valley in East Tyrol and Carinthia, where they lived – still in their units – as Surrendered Enemy Personnel of the British. About 25,000 Cossack and Caucasians arrived near Lienz.

Although the British administration promised they would be transferred to British Overseas Territories, the Cossack officers, soldiers and their families (about 22,500 people, including approximately 3,500 women and children) were handed over to the Soviet Troops. Around 4,100 were able to hide in the mountains and forests, and others decided to commit suicide. Some women jumped with their children into the river Drau, where they drowned, others gave their children to local families. The events became known as “the tragedy on the river Drau”. At least 1,350 Cossacks were recaptured. However, most of them were not handed over to the Soviet Union. They lived in a displaced persons camp in Lienz together with refugees mainly from Yugoslavia (Fig. 1a).

a *b*

Fig. 1. a) Everyday life at the Spittal displaced persons camp and b) Cossack women during her training as tailors, Spittal displaced persons camp (both © Joseph Plut, Toronto, Canada)

Exhibition Background

Until today, the Cossack’s tragedy of Lienz in 1945 has been and still is viewed primarily from the perspective of the men. Bold deeds, the magic of uniforms, medals, parades and other weapons as well as fateful comradeship were the focus of interest. The women in the retinue, who were not only of Cossack descent but came from many different countries, were left out. Many had joined the convoy in the hope of a better life in freedom. The exhibition tells the fates of these women, most of whom have remained behind the curtain of history (Fig. 1b).

The exhibition was scheduled to open on 1 June 2020 on the 75th anniversary of the Cossacks tragedy, but had to be re-planned as a virtual exhibition on short notice due to the restrictions during the Covid-19 crisis.

Part 2: The Creation of the Virtual Exhibition

The Virtual Reconstruction

After discussing several different possibilities for the realization, it was decided to virtually reconstruct the room of the Dolomite Bank, where the exhibition originally should have taken place, in order to provide the visitors with a genuine “feeling” of visiting the exhibition. Since it was not possible to visit the venue in person, the room was reconstructed in Blender (2019)[1] using a plan and a few photos (Fig. 2).

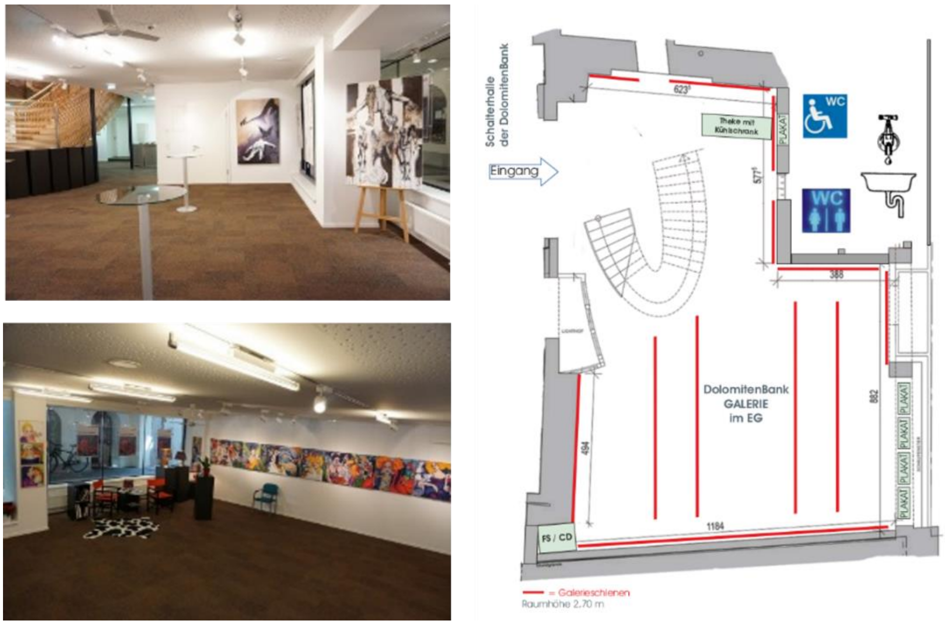

Fig. 2. Pictures and plan of the gallery of the Dolomites Bank (© Dolomitenbank, Lienz)

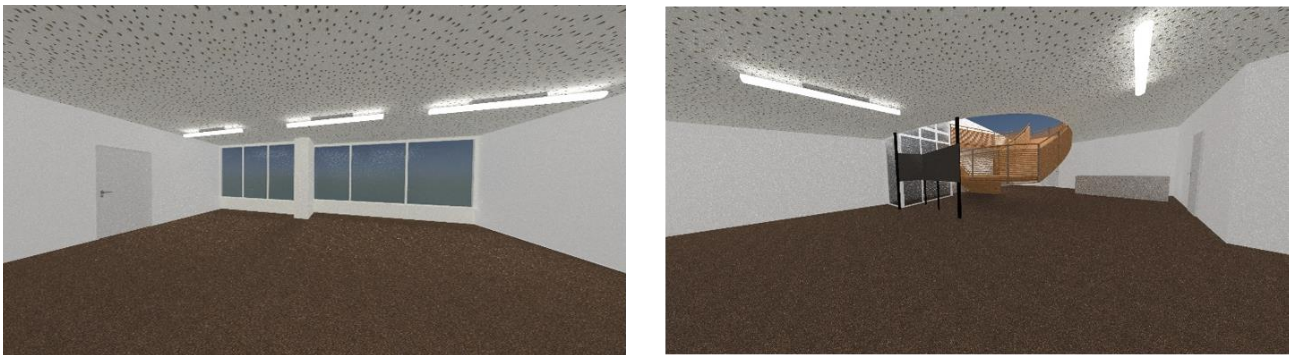

Fig. 3. Reconstructed Room in Blender (© Brigit Danthine)

Blender is an Open Source Software for modelling, texturing and animating 3D content. In the present case, the software was used to model the exhibition space as a 3D environment, to add architectural details such as the staircase or the showcases, as well as to create 3D models of finds like the ceremonial dagger and to add textures to everything. For specific architectural elements, such as the mentioned spiral staircase, the Archipack add-on (2018) was used. With this add-on for Blender it is possible to design and combine different architectural elements without having to model

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[1] The older version 2.79 was used for the reconstruction, since a completely new GUI was introduced with version 2.8. However, this did not result in any functional disadvantage.

every detail by hand. For example, a door can be created without modelling the door, the door frame and the door handles.

While this characteristic curved staircase already made the room recognizable as a replica of the gallery of the Dolomite Bank, the textures of e.g. ceiling, floor, lamps and staircase were selected according to the real conditions and added further for better recognition (Fig. 3).

Only one change was made compared to the real conditions to aid the usability of the virtual tour. The actual gallery of the Dolomite Bank is entered behind the stairs. For the virtual exhibition this would have meant that visitors would either have to "click" their way around the stairs, or that the exhibition would have been torn apart (Fig. 4). Neither would have been conducive to the user experience. Therefore, it was decided that visitors would enter the exhibition area via the actual restroom door, in this case acting as the exterior door in the virtual exhibition. Due to the position of this door, the user can overlook the entire room immediately after entering. This solution gives visitors the feeling of entering the virtual exhibition from the outside, without complicated navigation or confusing distribution of content.

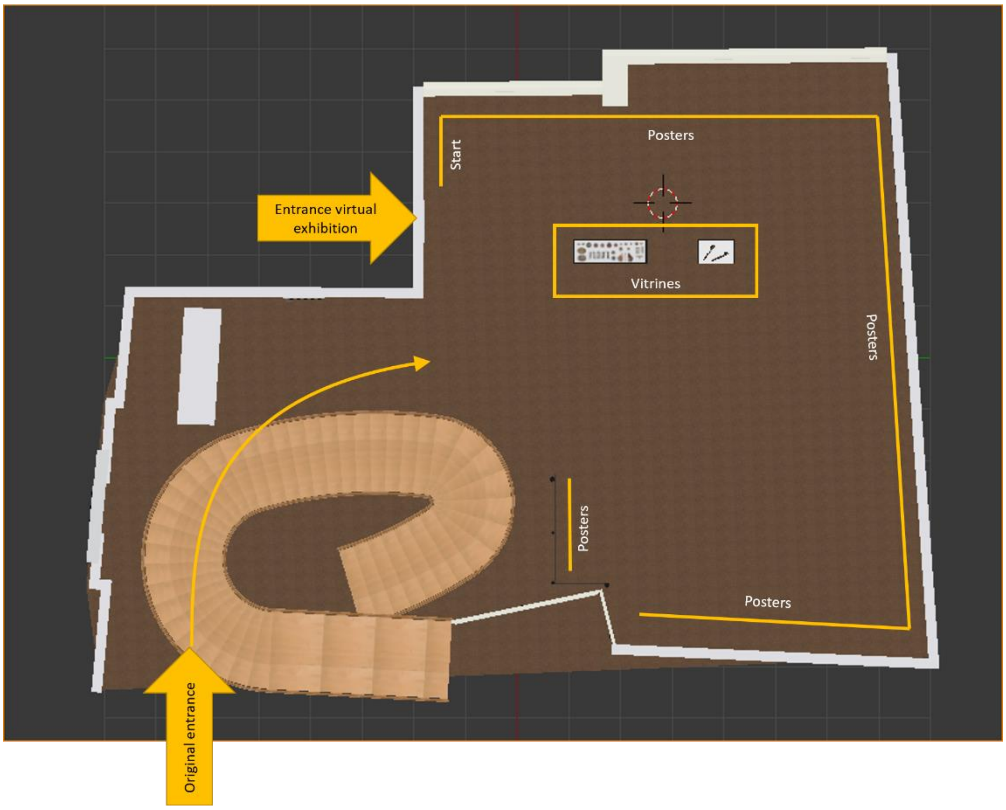

Fig. 4. Original entrance compared to virtual entry and visitor guidance (© Brigit Danthine)

In the reconstructed room, the posters of the exhibition were arranged along the walls according to their narrative sequence. Originally, it was planned that posters would also hang in the room along the picture rails in the floor plan (see Fig. 2). However, this was abandoned in favour of a better overview, otherwise visitors would not have been able to see the entire space from every position and that would have made orientation more difficult. This more "simple" layout, which probably has seemed a bit boring in an exhibition in a real physical environment is correspondingly a user advantage in the virtual space.

Fig. 5. Reconstructed room (© Brigit Danthine)

As planned, two showcases were reconstructed in the centre of the exhibition. In one of them, the finds of various surveys were arranged to show the spectrum of objects found. For the other smaller showcase, the outstanding find of a ceremonial dagger was reconstructed three-dimensionally with the corresponding UV-texture based on two find pictures (Fig. 5).

Fig. 6. Distorted, as it is a flat 360° image (© Brigit Danthine)

The Virtual Tour

In order to provide the visitors with a tour through the museum room with a full 360° view, several 360° pictures were rendered with the Cycles Render of Blender (Fig. 6). Cycles Render is an alternative render engine to the old Blender Render or the new Eevee Render pre-installed with every Blender version. Simplified, a render engine controls how surfaces of different objects are visualized. So these programs, in a sense, translate the 3D scenes into 2D images or animations. With this render engine, it is possible to render equirectangular panoramic images (Fig. 7).

Fig. 7. Camera position (highlighted in orange) of the different scenes (© Brigit Danthine)

The 360° pictures were then assembled into a "walkthrough tour" with the help of the Marzipano Tool (2020), a free interface for Marzipano (2020), which is an open-source 360° media framework. Within the Marzipano Tool, it is possible to link different 360° scenes with each other via link hotspots, so that the visitors can move from one camera position or scene to the next by clicking on the respective hotspots – similar to Google Street View. Within the tool, it is also possible to set up info hotspots. One was placed at each poster and object in the showcase.

After setting up this basic structure, the tour was exported as a folder structure with the images, the libraries and various javascript, html and css files – these are the three main languages or scripting languages that together make up a homepage. Reduced to the basic skeleton, css defines how something looks, the java-script-file controls the interactions and html is used to compose the content of the website.

Next, using the open-source text editor Notepad++ (2020), the information to be displayed within the hotspots was entered into the html and javascript files. While the artefacts in the large showcase were simple text and image blocks, the posters were not only to be displayed in large size, but info buttons at certain terms, places or persons offer the possibility to get further information about them. Unlike in a text, however, there is no way to hyperlink individual parts or specific pixels in images; only the whole image can link to something else. To still be able to place several different links at very specific parts of the image, a (transparent) svg overlay was "placed over" each image in every hotspot. Through this responsive svg-overlay it is possible to define specific shapes in certain sizes at positions defined by html, which link to other resources.[2] Finally, the 3-dimensional reconstruction of the ceremonial dagger was uploaded to Sketchfab, annotated and embedded as an iframe in the respective hotspot so that visitors can view it in full 3D from all sides. Sketchfab basically is for 3D content, what Youtube is for Videos: A platform to present the own content—in this case 3D models—to a community and the public.

After the appearance style of the virtual exhibition was defined via a correspondingly edited css-file, the entire folder structure was uploaded to the server and integrated on the homepage.

Part 3: The Virtual Exhibition

The final virtual exhibition now offers visitors the following options (Fig. 8): each image or scene can be viewed completely in 360°. The viewing angle can be changed either by clicking-and-dragging the mouse or by using the buttons located at the bottom of the screen. It is possible to switch between the different scenes either by using the link hotspots pointing in the corresponding direction of the new scene or by using the menu in the upper left corner. Above this menu are the buttons for showing and hiding the menu, as well as for autorotation—which is switched off by default—and full screen view. The posters as well as the information about the objects in the showcases can be opened by clicking on the info hotspots. The "eye button" in the upper right corner of the poster hotspots can also be used to open the posters as normal, machine-readable websites. The info buttons on the posters and on some find hotspots also link to further information.

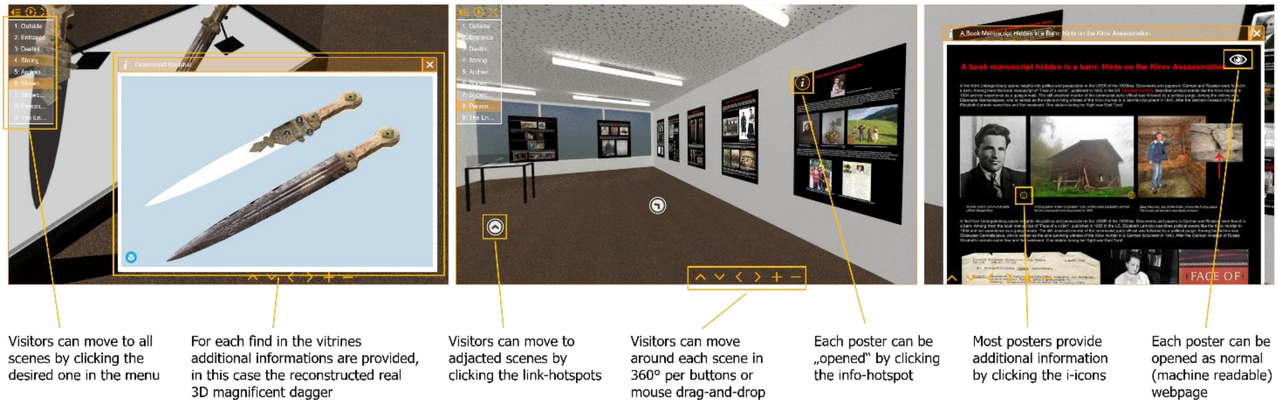

Fig. 8. Options of the visitors of the virtual exhibition (© Brigit Danthine)

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[2] A good overview of svg overlay options and possibilities can be found here: https://dev.to/damjess/responsive-svg-image-overlays-4bni

The virtual exhibition can be visited here:

https://www.kosaken-lienz1945.com/virtuelle-ausstellung--63364468-de.html

or by clicking on the desired language qr-code or by scanning the respective qr-code:

DE EN IT RU

Part 4: Advantages and Disadvantages of the Chosen Method

The advantages were that after the reconstruction in Blender all further work steps were relatively straightforward. Rendering the images only takes time, assembling the different scenes and integrating the hotspots for the different interactions is simple with the Marzipano Tool. The exported html, javascript and css files provide a good template so that they can be edited properly even with few scripting skills.

For 360° tours, various solutions are offered online. First of all, a distinction has to be made between mostly open-source frameworks and providers that also take care of hosting directly. While one of the former was chosen for this project with Marzipano, many commercial providers would have saved the last step of editing various files in scripting languages, as they offer a wider range of annotation and interaction possibilities. In the case of most commercial solutions, the respective annual fees are an obvious point to be considered. The free offered possibilities are mainly only available without an option of extension, and the data is then bound to exactly this solution. In contrast, frameworks like Marzipano offer more freedom to extend the possibilities by implementing the appropriate codes in html and javascript.

But whether open-source framework or commercial software or service, these solutions are based on 360° images that must first be rendered using Blender. This is a step that is not really necessary in this constellation, since the room is already 3-dimensional. Therefore, another possibility would have been to publish the room directly as a 3D model through which visitors can move. One solution specially developed for Blender would be for example blend4web (2021) or its (not Open Source) successor Verge3D (2022). Other open-source solutions are different frameworks like ThreeJS (2021), ATON (2021) or 3DHOP (2020) or game engines like Godot (2020). This would make it possible to publish not only 3D models for viewing, but also to provide them with appropriately defined interactions, camera positions or viewpoints. With this, the tour would have offered visitors the same possibilities of interactions. The advantage of this is evident: there is no need to render 360° images, as the 3-dimensional reconstruction itself is published directly. So, if a change of the reconstruction was necessary, it would be integrated directly without having to render new images first, which would then have to be integrated into the tour manually again. A small disadvantage, on the other hand, is that the Cycles renderer generates images that are closer to reality, so with a solution like blend4web or Verge3D, a reconstruction quickly looks a little flat.

However, it can be stated that in conclusion, the advantages of the chosen methods outweighed their disadvantages, which is why the approaches explained above were chosen.

Part 5: Future Prospects

In accordance with the FAIR principles, all files of the virtual exhibition (in packages of the particular language) were uploaded to Zenodo so that they are findable and accessible for everyone (Danthine et al., 2020a–d).

To make them also interoperable and reusable, the goal of a next project is to process the information about different objects, persons, places or events on the basis of the event-centered ontology CIDOC CRM (Fig. 9) (Bekiari et al., 2021) and to model it into a semantic network. With the help of this formalized ontology, which is focused on the cultural field, a wide variety of information can be formatted in a standardized way and linked with each other. Thus, it would not only be available for future projects, but could also be integrated on an international level with data edited by the same ontology.

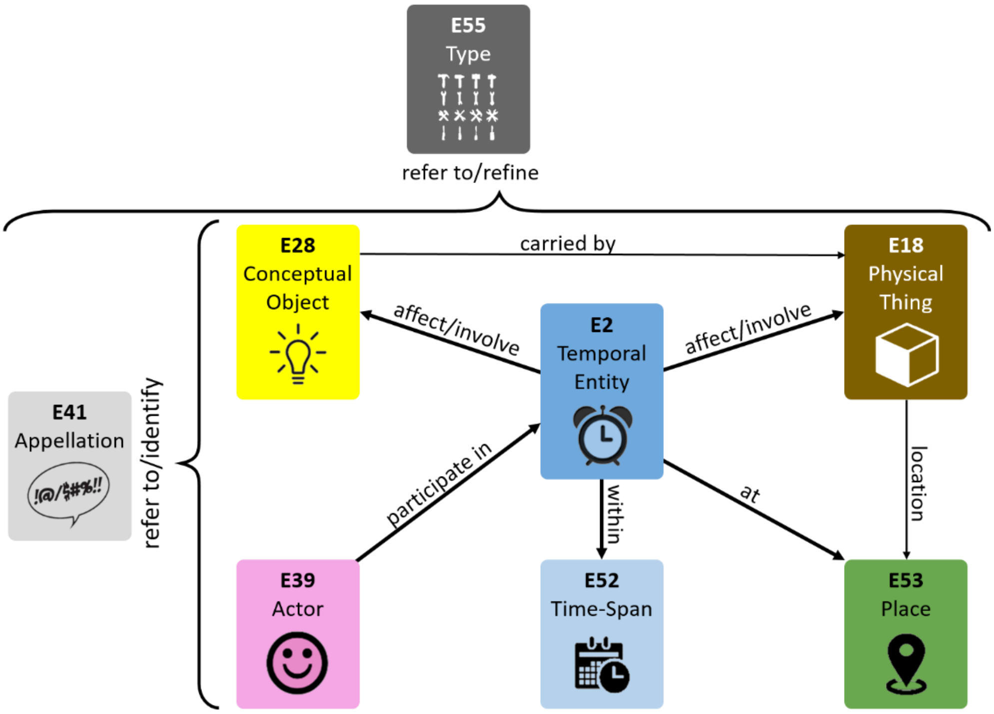

Fig. 9. CIDOC CRM classes (© Georg Bruseker)

In the future, both the standardized knowledge and other information such as pdf-files of technical papers (e.g. on academia.edu) or Wikipedia articles will be made accessible (e.g. the Yalta conference with https://de.wikipedia.org/wiki/Konferenz_von_Jalta). The texts within the virtual exhibition are accompanied by links that lead to information on the Internet, to locations in Google Maps or to nodes in the Knowledge Graph (Fig. 10).

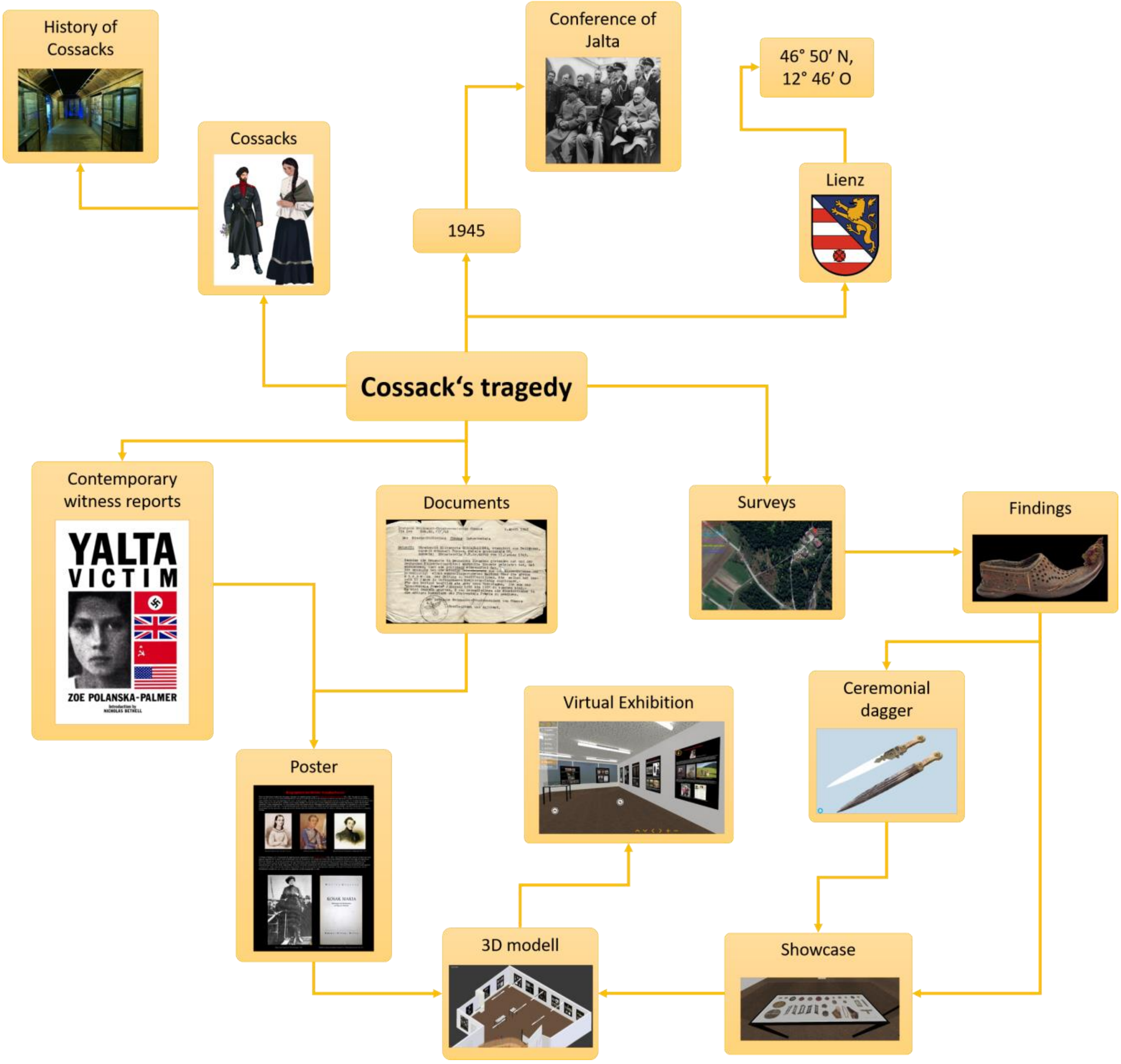

Fig. 10. Semantic linking of virtual exhibition and historical events with CIDOC CRM ontology (© f.t.l.t.b.r.: Andreas Blaickner, Institut for Archaeologies, University of Innsbruck; U.S. Signal Corps, Library of Congress, Franklin D, Roosevelt Library & Museum, Public Domain, Wikimedia Commons; Anna Pasechnik, Fulpmes; Archive of the Verein zum Gedenken an die Lienzer Kosakentragödie vom 1.6.1945; Institut for Archaeologies, University of Innsbruck; Google Earth; Tyrolean State Museum Ferdinandeum)

Special Thanks

A special thanks goes to all the contributors of the exhibition: Elisabeth Waldhart, Margarethe Oberdorfer, Andreas Blaickner (layout of the posters), Anna Pasechnik (title poster), Patrick Plaschg, Nikita Pasechnik (special contribution to exhibition poster), Elisa de Gaetani (Italian translation), Ksenia Scharr (Russian translation), Bernhard Nicolussi Castellan (editing of German texts), Maik Dienelt, Siegfried Dienelt, Mike Halbich, Michael Jost, Alexander Knapp, Lukas Kratzer, Thomas Perfler, Angelika Walder (archaeological surveys).

Also, our sincere gratitude to all the sponsors of the (virtual) exhibition: University of Innsbruck, Dolomite Bank, Flodin & Carstens GmbH, Rauchmehl, the Department of Culture Tyrol, Soroptimist International, Tourism Association East Tyrol.

Funding

Dolomitenbank, Lienz and *Verein zum Gedenken an die Lienzer Kosakentragödie vom 1. Juni 1945* (Association for the Commemoration of the Cossack Tragedy in Lienz on June 1, 1945) paid for the creation of the virtual exhibition.

The follow-up project mentioned in Part 5 was funded by the Research Center *Digital Humanities* of the University of Innsbruck as project of the *Digitalisierung und Informationsaufbereitung für die Digital Humanities* (Digitization and Information Processing for the Digital Humanities) initiative.

Conflict of Interests Disclosure

There are no financial or personal relationships to persons or organisations which could have influenced this article.

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3D documentation and virtual reconstruction of the castle of Waldstein

The combination of low-cost photogrammetry and a geodetic survey

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Keywords: *Geodesy—Reconstruction—Citizen participation*

CHNT Reference: Bauer, P. (2022). '3D documentation and virtual reconstruction of the castle of Waldstein', in Börner, W., Rohland, H., Kral-Börner, C. and Karner, L. (eds.) *Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020.* Heidelberg: Propylaeum.
doi:10.11588/propylaeum.1045.c14515

Introduction

The majority of historical castles in Austria are abandoned, exposed to wind and weather and slow decay. Because of their high importance as landmarks which have shaped the history of their nearby area for centuries, they deserve a detailed 3D documentation for the people and future scientists.

Terrestrial laser scanning and UAV imaginary have become state of the art methods for documentation in cultural heritage. However due to the high costs of a terrestrial laser scanning session and due to legal restrictions of drone surveys, these techniques are only applied to a selected number of historical sites of major public relevance.

The progress in photogrammetry has produced affordable software solutions which enable amateur users to simply derive 3D models with a handheld camera and a ruler. Although these models cannot compete with the accuracy of a professional survey, they offer an immense opportunity for gathering fast semantic and topological information of these structures for everyone.

Fig. 1. Group of volunteers at the first survey campaign (© Peter Bauer).

The Castle of Waldstein

Robert Baravalle (1961) writes in his book about Styrian castles, that Waldstein was founded at the end of the 11th century by Waldo of Ruen and has changed the ownership several times. Today's appearance of the main castle dates back to the 14th century and was extended with barbicans and two gatehouses in the 15th and 16th century. Because of the newly built residence in the valley, the castle was abandoned and left to decay at the beginning of the 17th century. Although it was open to the public till the end of the 20th century it is now closed to the public due to the danger of falling stones.

Survey Method

The aim of the survey was to update the hand drawn maps with modern total station measurements and to document the stonework of the inner castle and the remains of a Romanesque chapel in 3D.

For the 3D documentation a photogrammetric approach has been chosen. Therefore, the site has been photographed with SLR cameras by a group of volunteers under technical supervision. The focus of this first campaign was on a time and cost-efficient workflow. The images have been matched with low-cost software and the resulting point clouds have been scaled with photo scales, which have been placed into the scenes. Hereby the most significant remains of the castle have been documented in a single day of fieldwork.

Afterwards the scaled point clouds have been geo-referenced with airborne images and LiDAR data, which are accessible to the public by the open GIS of the Austrian government. The horizontal co-ordinates of corners and edges of the 3D point clouds have been extracted from the rectified and georeferenced airborne images. The national digital terrain model (DGM) has been used to give the local point clouds an approximate hight. This workflow has provided an adequate three-dimensional representation of the castle complex with minor accuracy demands, which served as a data foundation for further detailed investigations.

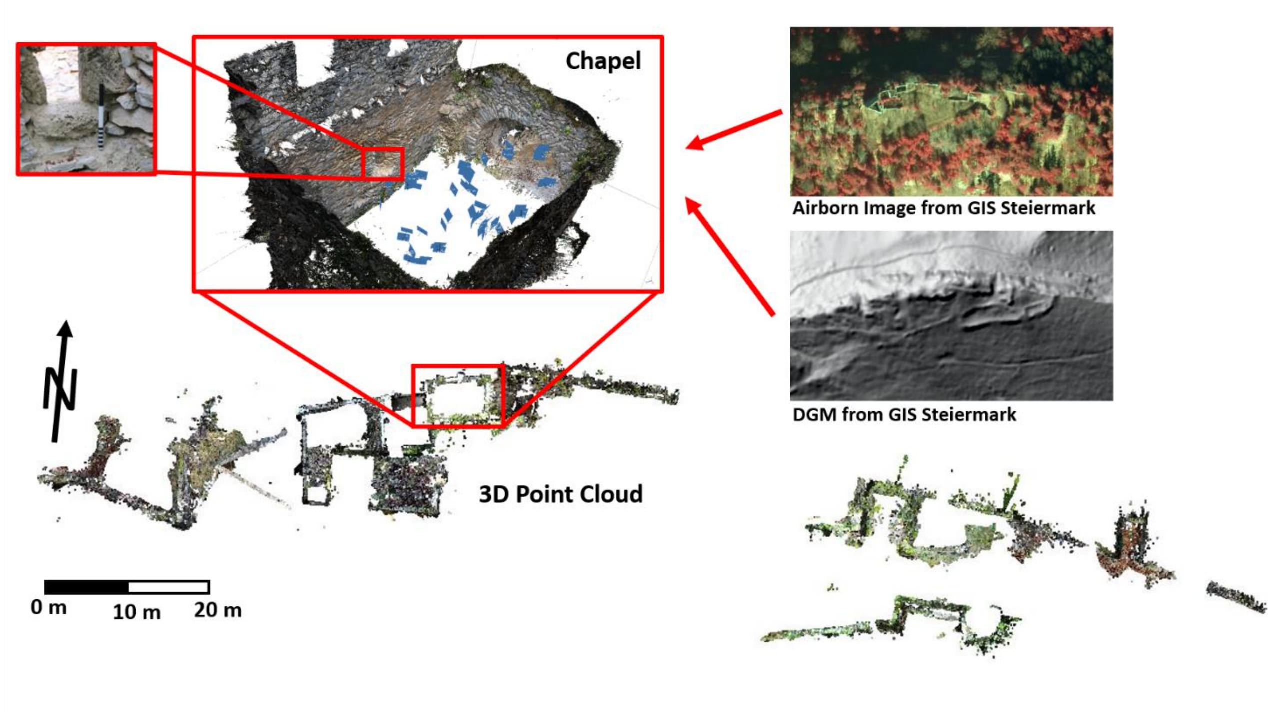

Fig. 2. 3D point cloud produced with low cost photogrammetry and open government data (© Peter Bauer).

In a second campaign, measurements with a total station and a geodetic GNSS device have been carried out to produce a highly accurate 3D model of the former castle Waldstein. In addition to the location of the barbicans, also key features in the High castle have been measured, which were visible in the amateur images of the first campaign. These keypoints and the technical supervision of the first campaign made it possible to process the amateur images with professional software. This improved 3D point cloud and the total station measurements have been the basis for a detailed 3D reconstruction.

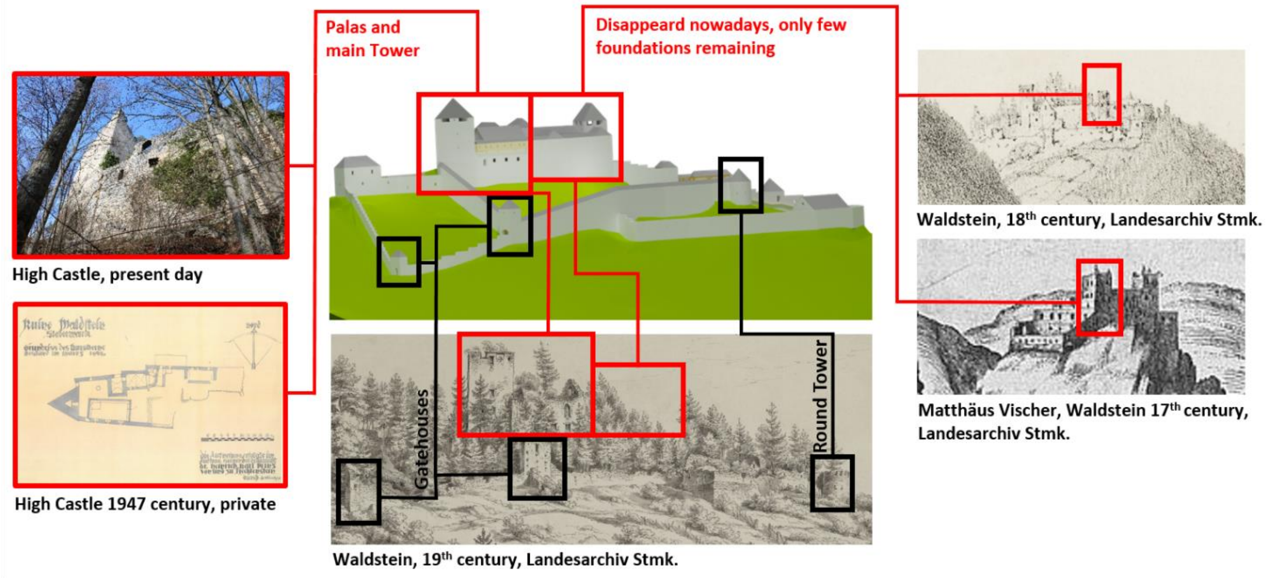

Fig. 3. 3D reconstruction of the castle Waldstein [1].(© Peter Bauer).

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[1] http://igms.3dworld.tugraz.at/HomepageWaldstein.html

The appearance of the castle has been modelled according to old plans provided by the castle owner and according to historic drawings from the Landesarchiv Steiermark. During the modelling process valuable inspiration has been found in Otto Pipers books (1902) and (1912).

Conclusion

Introducing citizens into the basics of photogrammetry raises the public interest for historic structures. Motivating them in capturing and sharing photogrammetry-ready images can lead to a larger coverage and better temporal resolution of historic spatial data. Although low cost photogrammetric point clouds can have absolute deviations of a few decimetres (in this case verified with total station measurements) the relative accuracy is sufficient for the adequate representation of the used stonework and construction phases, if these historic sites disappear before a professional documentation could have taken place. The largest benefit for the investigation of these sites, can be seen in the combination of this amateur photogrammetry and professional terrestrial surveys with total stations or laser scanners (TLS). The gathered photogrammetric raw data can be taken into account any time in the future, as long as some key features of the structure survive over time to create ground control points.

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Urban digitalisation

The survey of Bertinoro

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Keywords: *Photogrammetry—Drone—Digitalisation—Historic Fortress—Aviation regulation*

CHNT Reference: Pasquali, A., Giraudeau, S., and Capparelli, F. (2022). ‘Urban digitalisation. The survey of Bertinoro’, in Börner, W., Rohland, H., Kral-Börner, C. and Karner, L. (eds.) *Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020.* Heidelberg: Propylaeum.
doi:10.11588/propylaeum.1045.c14516

The paper proposes the steps of study and elaboration carried out on the historical village of Bertinoro. Bertinoro is a town in the province of Forlì, on the Italian Adriatic coast. The work carried out on this historical town consists of three phases.

A first phase was that of the survey, executed in situ with digital technologies. In this phase laser-scanner survey and photographic survey aimed to perform digital photogrammetry. the most interesting component of this first phase was the photographic survey. the survey aimed at photogrammetry was organized both on a terrestrial campaign and an aerial one structured on various flights performed by drone. For the ground shots a full frame Nikon D610 camera with Nikkor 24–120 mm f3.5–5.6 lens was used, while for the flights the drone used was a Parrot Anafi. The drone weight was reduced to 300 gr. in order to perform non-critical operations in an urban context, as required by current legislation. This organization is due to the morphological characteristics of the urban system. Bertinoro is a small village, perched on Mount Maggio at an altitude of 328 meters and about 20 kilometers from the Adriatic Sea. Its position and urban structure allow to connect the village to a military past. The organization of the defensive structures and the position on the hill allow to identify the village as a sighting component towards the coast. The urban morphology is structured with a very compact historical architectural system because it is organized within the defensive walls. The road system and the urban voids are very limited and with rather small dimensions. For this reason, it was necessary to resort to the abovementioned organizational strategy for the photographic survey. Several portions of the urban fronts were poorly acquired with aerial photographs, the risk of obtaining an unclear survey or with a strong error was considered high. Therefore, a terrestrial photographic survey campaign was implemented in order to complete the data with closer and more controlled shots.

The second phase concerns the collection of documentary information. Carried out with archival research and interviews on the population, it has allowed to deepen details and events related to the history of Bertinoro. The survey phase and this last one make up the cognitive component of study subject. These two phases have made it possible to outline a complete documental picture, collecting different types of documentation in digital format and generating a potential archival component for future studies.

The last phase was the processing of the collected material. The main focus of this contribution is on the processing phase of the digital survey data. The primary operations of control and indexing of the data acquired by laser-scanner are part of usual operational practices. These operations have given the result of the global point cloud of the historicized urban system. The data collected is organized on 515 scans done with a scanner FARO Focus 3D X330. We opted for variable instrument setting choices, depending on the characteristics of the environment to be detected. In general, we have chosen to give priority to the completeness of the data, with a more number of scans, rather than their accuracy. This has allowed us to have faster scansions in larger numbers. obtaining monochromatic point clouds. the most interesting part of this phase is the processing of the photographic images. This step involved software operations for digital photogrammetry with the main target to obtain a 3D model with texture. The digital images processed were 5426, divided into 3302 obtained from flights and 2124 from ground shots. This component of the work was the most relevant, both in terms of work and observations found in the process. The processing required a significant amount of time and the results obtained formed a vast group of results. The accuracy of the results and the timing made us choose to structure the calculations functional to the results to be obtained. By composing a set containing both a total model of the whole urban nucleus and secondary models of smaller portions. The latter are smaller in size and therefore more accurate and denser in detail.

All the products of the research and work have formed a set of new digital information accessible by scholars, the municipality and local associations. At the head of this research work there were two main purposes: the first, more relevant for scholars and intellectuals, is the creation of materials

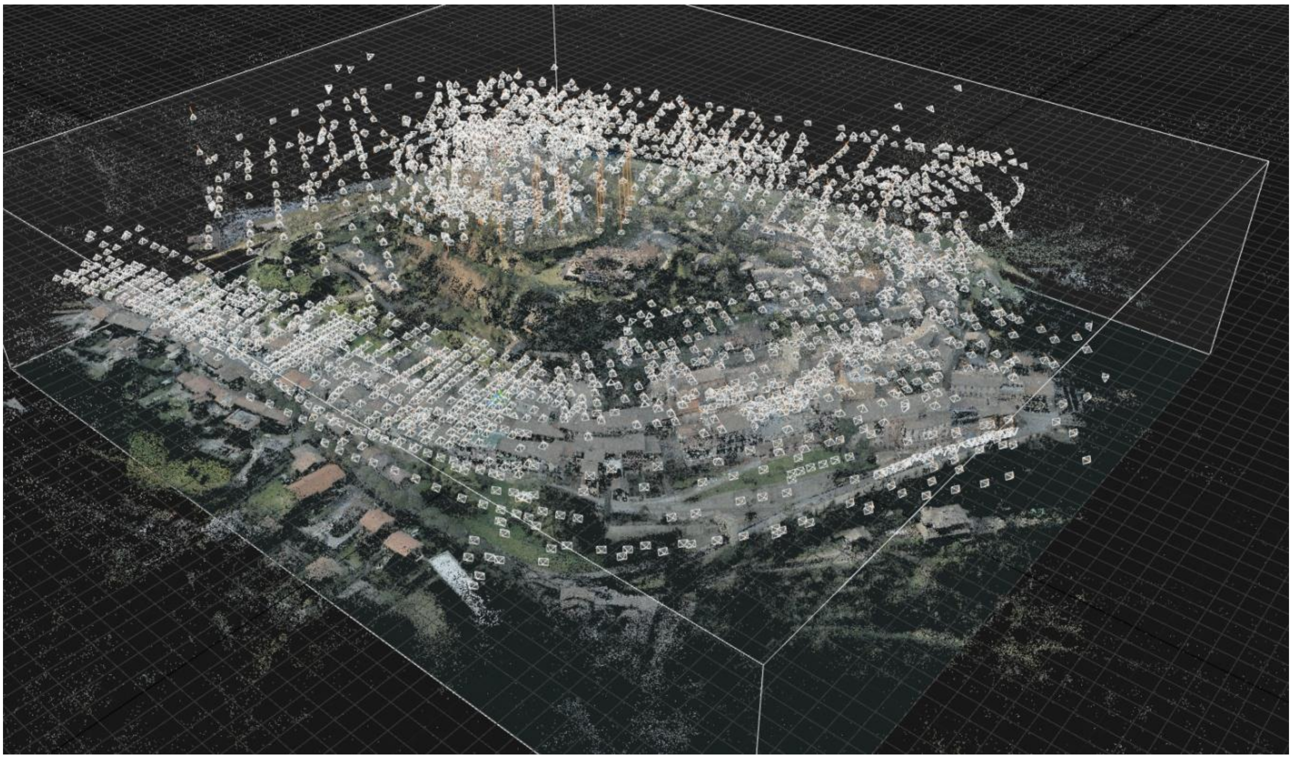

Fig. 1. Screenshot 3D Bertinoro (© Giraudeau, Pasquali, Cappatelli).

useful to the knowledge of the relevant historical elements, the Fortress and the Wall System; the second, of public interest and useful to the consolidation of a security system of citizenship, was to provide the documentary basis for the drafting of the CLE document. The Italian national document for the analysis of the Limit Conditions for the Emergency, useful for the evaluation in the drafting of operational intervention plans and the improvement of actions in case of seismic events.

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Towards a Computerized Physical Architectural Model

Aldo Rossi and the Theatre of the World

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Keywords: *Digital Models—3D Printing—Augmented Reality—Extended Reality—Virtual Reconstruction*

CHNT Reference: Galatolo, O. and Cecconi, E. (2022). 'Towards a Computerized Physical Architectural Model', in Börner, W., Rohland, H., Kral-Börner, C. and Karner, L. (eds.) *Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020.* Heidelberg: Propylaeum.
doi:10.11588/propylaeum.1045.c14517

Introduction

The growing interest on digital technologies let Virtual Reality (VR) and Augmented Reality (AR) become tools widely used for the conservation, representation and dissemination of Cultural Heritage (Bekele and Champion, 2019, p. 1). Over the last years, museums and cultural institutions offers to visitors a combination of historical and artistic heritage material objects and digital/non-physical contents: heritage is made available through the integration of multiple interactive and multimedia experiences in order to stimulate involvement and improve user learning. On the assumption that the architectural model is to be considered a cultural heritage, this contribution intends to examine and explore his expressive and communicative potentials in the light of the aforementioned interactive digital new technologies. The first part of the study presents an overview of the solutions already integrating physical models and digital technologies. The second part describes the conceptual and practical work ongoing on architecture models at the Architecture Models Laboratory (LMA) with the collaboration of the Extended Realities Laboratory (LXR) at the Architecture Department of the University of Florence, taking as an example the model of Teatro del Mondo by Aldo Rossi.

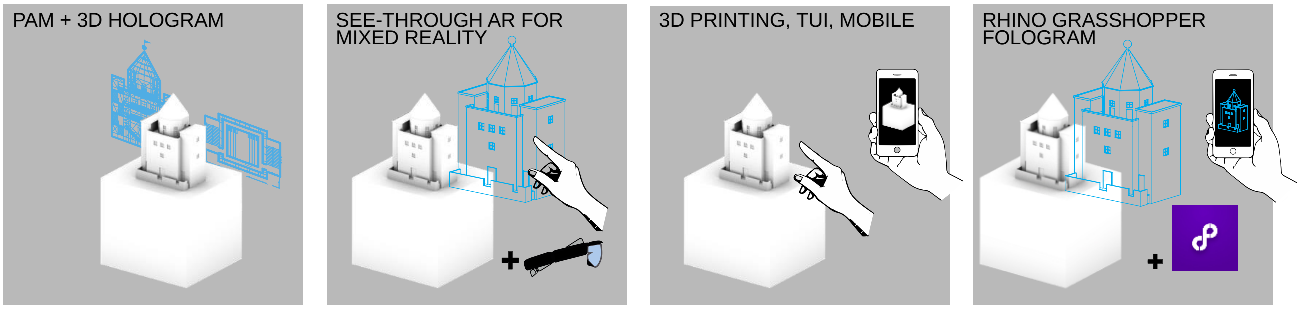

Fig. 1. Graphical summary of possible interactions between PhAM and digital contents

The Material and the Imaginary: on Mixed Reality and Physical Architectural Model

The physical model displays the three spatial dimensions simultaneously: as an abstract and simplified representation, it shows otherwise unintelligible concepts and principles to the eye. In relation to the new dematerialized scenarios offered by digital technologies, in order not to lose the object value of the physical architectural model (PhAM), a question is here proposed: is there an interface that allows integrating the imaginary, the virtual reality of the immersive experience with the physical reality of the material model? What are the experiences carried out until now and which are the possible developments?

To answer these questions, the research was carried out by examining scientific publications and articles in specialized online journals and consider the exhibition methods of some museums or architecture events. The possibility to integrate physical model with digital contents is not a new topic. Contributions to this purpose come from different fields of studies and have been applied with more or less success to the architectural model since the end of the Nineties (Milanovic et al., 2017).

Thanks to this overview, different modes and levels of interaction can be identified: from technologies which only allow remote observation or others requiring the use of a personal device and a simple application, to systems providing the ability to interact with the physical object (usually replicas) through touch. Interactions and augmented experiences with PhAM can occur even through a system application specially designed for that object (Fig. 1, Table 1).

The more complex and articulated interactions are possible thanks to Mixed Reality systems; the use of devices such as AR reading glasses, makes the surrounding reality added with digital and sometimes dynamic objects, also reactive to certain gestures. This interaction mode was tested by Greg Lynn (2016) during the Venice Biennale, enabling him to propose to visitors a way of acting on the PM by recalling information through gestures and viewing them through the device provided, i.e. Trimble Connect with Hololens. The Arctron 3D Company (2020) offers combined solutions of VR and AR experience and also of the use of hologram display systems combined with historical models or miniatures of artworks. As part of the teaching about urban and architectural design, the interaction between digital and physical has given rise to a prototype that allows the manipulation of physical objects printed with conductive materials and the consequent visualization on tablets or smartphones of the volumes modified by acting on objects (Narazani et al., 2019). Compliant with the use of Rhinoceros and Grasshopper, Fologram (2020) is an AR software to be used with Hololens or directly via tablets and smartphones. It generates contents from superimposing physical reality through AR. In his interesting work and experimentations, Nofal (2019) examined how tangible interaction can be used on physical models, to enable the communication of qualitative information about a built heritage. In Table n.1 these systems are summarized and briefly described.

Table 1. General overview on systems which combines PhAM and digital contents.

System	Short Description
PhAM + Hologram	The historical PhAM stands inside a glass box, contents are displayed aside the model and only remote observation is allowed.
PhAM + Qr code	Insertion of a Qr code in the PhAM, referring to multimedia contents regarding the original project and the model itself.
Image recognition App	Image recognition APP of the model by scanning and obtaining information found on the internet.

Rhino + Fologram (AR)	Through Fologram, an Augmented Reality APP, holdin a smartphone or a tablet, 3D models created with Rhinoceros CAD can be superimposed in the space surrounding the model and the user.
See through AR	Wearing an HMD the user can see the real world with computer-generated information superimposed on top and interact with gestures.
3d printing TUI	Combining a mobile, an app and 3d printed tangible objects (made with conductive materials or other techniques) it is possible to create a virtual model involving the visitor in a personal interaction with the model.
Phygital Heritage	In his PhD thesis, Nofal (2019) presents the original approach of *“Phygital Heritage*”, intending to disclose heritage information via simultaneous and integrated physical and digital means. The four studies conducted are examples of the interaction technologies systems to connect physical and digital experience: a tangible interactive museum prototype, an augmented reality experience, an in-situ interactive projection mapping, a tangible gamification installation.
Projection Augmented Model	A physical three-dimensional model, touchable, onto which a computer image is projected to create a realistic looking object or to visualize other information

Aldo Rossi and the Theatre of the World: Model Making

The physical architectural model, as a synthetic representation, has been used for centuries to facilitate the understanding of objects that are complex or dimensionally too large to be understood in their entirety. Unlike the digital 3D model, the PM is capable of establishing a lasting and stable cognitive relationship with the one who looks at it. But is this very materiality of the PM that makes it impossible to obtain a series of information. In the PM, matter, context, construction often remain in a state of generic analogical simulation. If, thanks to the immateriality of digital elaborations, the shape of the space acquires further possibilities, its description must be subject to the rules of construction: first of all, the reproduction scale dictates the conscious omission of a series of information in favour of a better overall readability of the project. Attempts to overcome this limit have generated historical examples, first among which are the sixteenth gargantuan models for St. Peter’s Basilica in Rome. The AR lays the foundations for a possible overcoming of this limit, giving the possibility of integrating information relating to the material to the construction systems in a small size model, to insert it into the context without the need to create large models such as that of the ‘basilica that is not there’ of San Gallo (Zander, 2018, p. 4). The proposed example, Aldo Rossi’s Theatre of the World, was selected because, similarly to the Sangallo cathedral, it ‘does not exist’. Designed and built by Aldo Rossi for the 1980 Venice Biennale, it was dismantled the year following its inauguration, at the end of his legendary journey across the Adriatic. The small architecture was then rebuilt in 2004 in Genoa, only to be dismantled again. Its physical figuration through the material model was conceived precisely for this ephemeral characteristic, for its absence: it almost expresses the need for a simulacrum, capable of recalling the photographic images of his first appearance, which proposed him as a specular abstraction of the customs point to which it was anchored.

The realization of the PM of this little architecture imposes particular difficulties: if externally the metaphysical volumes of which it is composed are easily achievable with multiple technologies (from 3D printing to the more traditional woodworking), the internal construction system consists of an intricate mesh of thin tubular, whose scale representation would undergo such a resizing as to invalidate a correct description of the work (see Fig. 5).

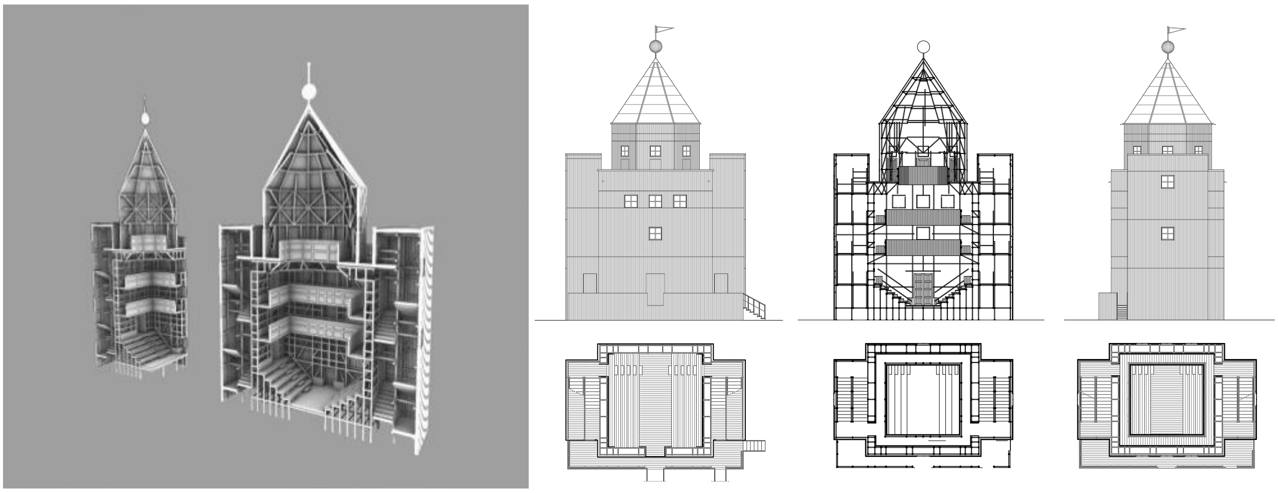

Fig. 2. 2D drawing and 3D modelling in Rhino by Enrico Pupi.

Reconstructed on the drawings published by Francesco Fera (2009, pp. 128–137), the original 2D drawings were reproduced and subsequently 3D modelling was carried out through the use of McNeel Rhinoceros and Grasshopper (see Fig. 2). In this popular plugin based on a visual programming language and environment, a specific script capable of controlling the size of the tubular section of the internal structure has been created, in order to adapt them to the 3D printing types and to the various scales of representation. It has been noted, however, that even using techniques such as laser sintering, capable of a high level of detail, it is not possible to achieve a perceptually correct conjugation between the section of the structure and the size of the architecture that contains it (Fig. 3).

In order to represent the structure, it was decided to start an evaluation on the possible interactions with the AR, to verify if and how the conjugation between the two technologies may fill this gap. The system chosen for the initial experimentation was QR code insertion on the PM of Teatro del Mondo.

By framing the code, it is possible to gain access to a public Drive folder containing information about the project and the model, also coming from the studies conducted by Enrico Pupi during his internship at the Architectural Models Lab: 2D drawings, 3D models for 3D printings, references, more graphic information, a specific bibliography etc.

a *b* *c*

Fig. 3. 3D print of Teatro del Mondo, material: white PLA, printer: Raise

The purpose to distribute the results of the many internship courses carried out within the DidaLabs Laboratory System is thus made possible thanks to the current digital resources, accessible from the major online platforms, disposing a link with specific resources and reachable by everyone in an easy manner.

The 3D CAD material obtained from the internship was necessarily reworked thanks to Ylenia Ricci from the Extended Reality Lab (LXR) for the production of virtual contents via Cinema 4D and Unreal (Verdiani et al., 2020, see Fig. 4–6). This virtual content has been added to the public Drive folder and can also be experienced with immersive Head Mounted devices.

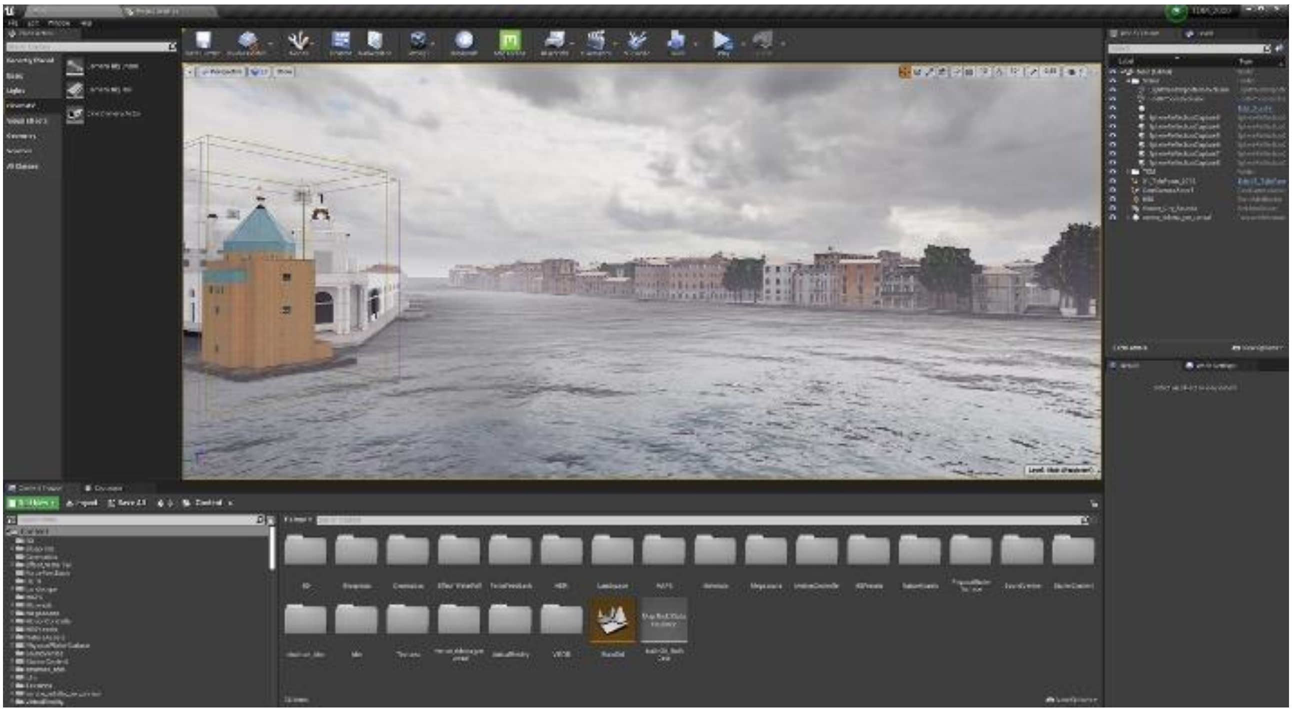

Fig. 4. A screenshot from the working configuration in Unreal Engine, Image by Ylenia Ricci (LXR Dildalabs).

Conclusions and perspectives

Thinking about some practical uses of the above-mentioned systems in model making techniques, it can be hypothesized to use AR systems such Fologram with Hololens as an aid in visualizing the PM before its construction, and as a guide to its construction. In the exhibition context, it could be used to understand the construction of the model but also to give information on the project.

The Smithsonian Institution Digitization Program Office focuses on developing solutions to further the Smithsonian's mission of "the Increase and diffusion of knowledge" through the use of three-dimensional capture technology, analysis tools, and distribution platform. Thanks to this program through the online museum platform, various digital 3D models are made available free of charge in various formats, for viewing only or even for printing. Taking as an example the experience of the Smithsonian, we could hypothesize to apply this process to architecture. To facilitate and spread the physical and tangible experience with the architectural model, it can be suggested to set an online platform where offer free access to 3D architectural models, printable by schools or for personal use, to physically interact with: the possibility of fixing a personalized point of view on the scaled object is what makes the PhAM unique and indispensable. In addition, having a material object could act as a bridge between a visit to the museum and an online digital experience, which could be applied also to PM, not only to cultural heritage objects as replicas (Petrelli et al., 2017).

Fig. 5. Possible contents: a view of the interior structure of the Theatre, Image by Ylenia Ricci (LXR Dildalabs).

The latest development of this ongoing research led to testing the model itself as a marker: the physical model printed in 3D FDM was scanned and subsequently processed on Arkit for iOs and XCode, version Reality Composer. The use of AI for image recognition and the integration of search systems within the major platforms allows the use of the physical model as a link. Not only through the insertion of specific QR codes but also through its clear aesthetic identification. In this way, through the physical model, an interaction is activated that allows the user both to manipulate the digital version of the model and to reach detailed contents on the project.

The current high availability of online applications, devices and platforms for sharing digital 3D models, combined with the increasing deployment of rapid prototyping technologies, could be a further boost to the development of new augmented architectural models and new interaction modes.

Fig. 6. Possible contents: The Theatre and the Venice Lagoon, by Ylenia Ricci (LXR Dildalabs).

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Identifying Historical Objects by Using Computer Vision

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Keywords: *Artificial Intelligence—Computer Vision—Art History—Museum—Digital Humanities*

CHNT Reference: Perera, W. L., Messemer, H., Heinz, M., and Kretzschmar, M. (2022). 'Identifying Historical Objects by Using Computer Vision', in Börner, W., Rohland, H., Kral-Börner, C. and Karner, L. (eds.) Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020. Heidelberg: Propylaeum.
doi:10.11588/propylaeum.1045.c14518

Introduction

Museums all over the world collect and present an uncountable number of precious objects to preserve the cultural heritage of mankind. These artworks are subject to the study of scholars, students and the general public alike. Advancing information delivery systems to provide data of these objects would be of great value not only to speed up research but also to significantly facilitate students in studying the artworks. To create such systems, it is essential to identify artworks correctly. This can be achieved with the help of computer vision technologies in artificial intelligence (AI).

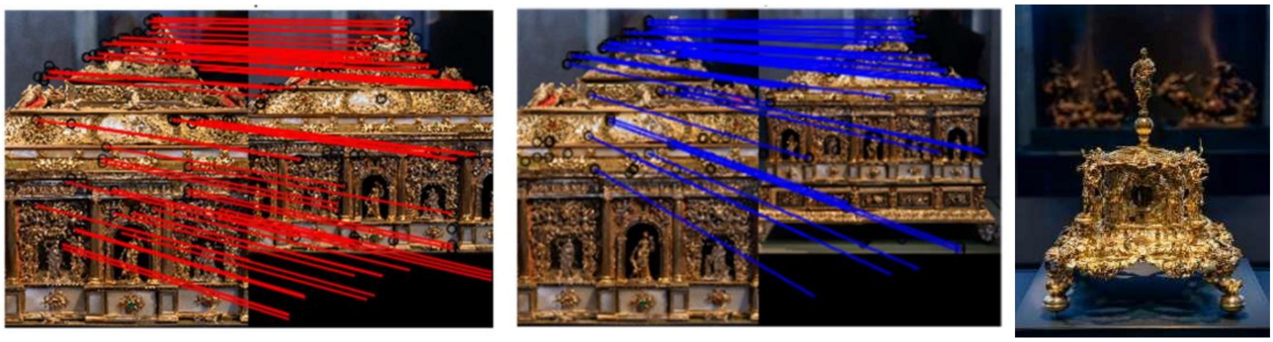
Aims and Methodology

It will be demonstrated how precious artworks of the museum New Green Vault in Dresden, Germany, are identified with computer vision. Therefore, outstanding artworks of the courtly collection, which date back to the 1560s, were photographed in high resolution. The compiled dataset comprises 105 objects and 70 images.

To identify particular artworks on the images as well as to retrieve images from the Dresden Treasures Dataset, DELF, a neural network model published by Google, and the algorithm RANSAC were used. Furthermore, several libraries (Matplotlib, NumPy, Scipy, Keras) were used in combination with Python code to process the model.

Results

The method used for image retrieval is shown with images of the Large Display Casket Belonging to Sophia as an example. How the images were correctly retrieved and incorrect images were skipped is displayed in Figure 1. Features of the images were detected and key points were selected to match them with other images in the images folder. Inliers were realized so that images with higher inlier counts could be matched with the reference image and be retrieved (Fig. 1). This convolutional neural network-based model is sufficient to obtain both key points and descriptors (Noh et al., 2017).



1 2 3

Fig. 1. Retrieving images of the Large Display Casket Belonging to Sophia, Consort of the Elector (ca 1588, Inv.No.IV 115, Staatliche Kunstsammlungen Dresden, Germany; photos: Michael Kretzschmar). Comparison 1–2 = 1; Comparison 2–3 = 0; Comparison 1–3 = 0.

For the test displayed in Figure 1 the desired result is 1,0,0, indicating that image 1 should be matched with image 2 as both depict the Large Display Casket Belonging to Sophia. Image 1 and 2 should not be matched with image 3, because image 3 does not represent the Large Display Casket Belonging to Sophia.

By using the methodology, which was discussed in the Aims and Methodology section, final tests were performed. The results of the tests were processed through confusion matrix calculations.

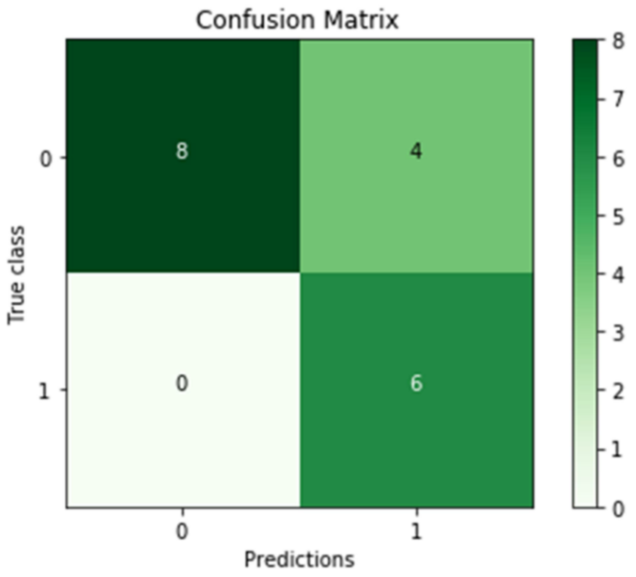


Fig. 2. Confusion Matrix results of image retrieval of the historical objects.

The results of the confusion matrix are:

y_actual = 1,0,0, 1,0,0, 1,0,0, 1,0,0, 1,0,0, 1,0,0 (desired result) and y_predicted = 1,1,1, 1,0,0, 1,1,1, 1,0,0, 1,0,0, 1,0,0 (predicted result).

In detail this means as shown in Figure 2:

Number of False Negatives = 0

Number of True Positives = 6

Number of True Negative = 8

Number of False Positives = 4

The results state that the accuracy of the Confusion Matrix calculations is 78% ($accuracy = (true\ positives + true\ negatives) / (true\ positives + true\ negatives + false\ positive + false\ negatives)$). The precision is 60% ($precision = true\ positives / (true\ positives + false\ positives)$). The recall score is 100% ($recall\ score = true\ positives / (true\ positives + false\ negatives)$) (Manliguez, 2016).

Discussion

As shown the used methods for image retrieval of photographs displaying historical objects were suitable for this task. With the amount of data growing rapidly, AI is getting increasingly important in the field of digital humanities in general. In the field of art history in specific, more and more projects using AI are developed since the 2010s (Bell and Ommer, 2018). This abstract demonstrated that object recognition in computer vision has the potential to be a fruitful research area for the field of art history. AI will also create innovative possibilities in higher education in the long run (Pence, 2019). Especially in the context of large datasets including a growing number of images and corresponding metadata this technology is necessary to process, to filter, to present and to analyse them as well as to provide correct metadata. “The best arrangement will be a division of labour, AI does what it does best, and humans do what they do best” (Pence, 2019, p. 11).

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The virtual model in archaeology

Continuity of the 3D medium in documentation, reconstruction, and publication.

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Keywords: *3D Modelling—Hypothesis Modelling—Virtual Reconstruction—Structure From Motion—Interactive Prototype*

CHNT Reference: Bruderer, O. (2022). 'The virtual model in archaeology. Continuity of the 3D medium in documentation, reconstruction, and publication', in Börner, W., Rohland, H., Kral-Börner, C. and Karner, L. (eds.) *Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020*. Heidelberg: Propylaeum.
doi:10.11588/propylaeum.1045.c14519

Introduction

The 3D medium sees its application within archaeology in many shapes and for various purposes. The documentation of findings with Structure from Motion (SfM), the virtual reconstruction of architecture through 3d modelling software or the communication of research to a broader public through VR are some examples for these. This project around the virtual reconstruction of an ancient stoa in Amarynthos1 paid attention to the complete visualisation process rather than just focusing on one single aspect. Observing the use of the 3D medium from the field documentation till the digital publication allowed to better understand the potential the various forms of the medium bring. It involves reflection on how information gets preserved, generated or constructed at the different stages, and how the 3D models can be transformed and used at the next stage. This finally helps to develop 3D workflows and thus to establish the medium within archaeology as a common tool for documentation, research and communication. This paper and especially the poster which it describes offer one such solution in an applied example and contribute to the ongoing discussion on how the 3D medium can and should be used successfully within archaeology.

Documentation

The objects of research in archaeology are usually bound to a specific location, even more so when it comes to the remains of architecture. Quite often the context gets also irrevocably altered or lost during the excavation process. The basis of any further research and communication is thus the documentation, with its form and quality being crucial for any work beyond the site. An important part of it is visual information, represented through drawings, photographs, 3D models, etc.

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[1] The paper is based on the master studies diploma project of the author, which successfully graduated in summer 2020 at the Zurich University of the Arts. The project continued as a research project at the Zurich University of the Arts (ZHdK). The virtual reconstruction model of a late classical / early hellenistic stoa was elaborated together with the Swiss School of Archaeology in Greece (ESAG). The ESAG conducts excavations at the sanctuary of Artemis in Amarynthos, in collaboration with the Ephorate of Antiquities of Euboea. For further informations about the excavation project visit: www.esag.swiss/amarynthos/

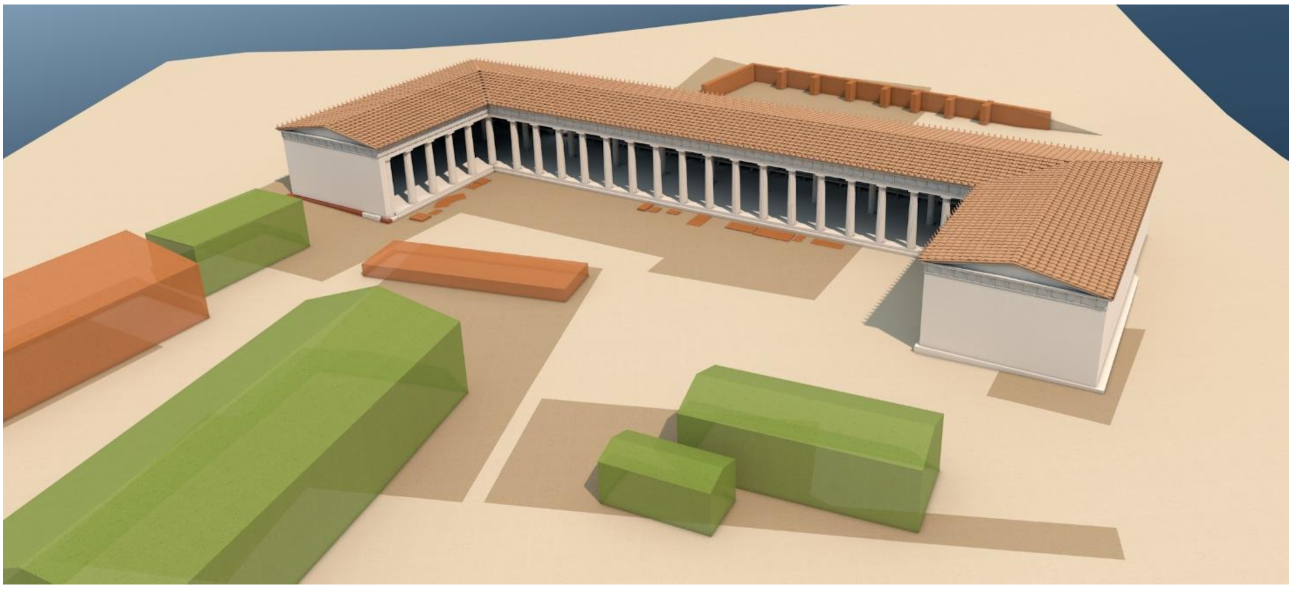

Fig. 1. Final reconstruction model of the stoa. The buildings around are still part of ongoing research and thus shown in an abstract shape. The colours represent the period of their construction: green – classical; orange – hellenistic. The darker fields on the ground represent the currently excavated areas. (© O. Bruderer, ZHdK / ESAG).

The reconstruction of the stoa of Amarynthos started with the documentation of the relevant findings, besides the fundaments still in situ these were mainly fragments of architectural elements. In addition to drawings, the objects and structures were documented with *Structure from Motion (SfM)*. That allowed to generate textured polygonal models of all findings, ready for use in virtual 3D space.

It is important to note that besides all the benefits of 3D technology, the drawings of these objects and structures remain an important part of the documentation. The automatically generated 3D data via *SfM* consist solely of surface data in the form of polygons and pixels (or points in the case of point clouds), and do not contain any archaeological interpretation. They are quite the opposite of field drawings or find illustrations produced by observation of the original object, thus representing a first interpretation by the drawing person.

Reconstruction modelling

One of the main benefits of 3D modelling for archaeological research is given by the possibilities to (re-)construct the appearance of architecture or artefacts. The modelling allows to evaluate the available evidence, develop hypothesis and construct multiple solutions where clear findings are lacking, offering a perceptival basis for the discussion between experts.

The way these reconstruction models are built depends largely on the available data as well as the project goals. A wide variety of project goals come into consideration for a virtual reconstruction, as discussed for example thoroughly in Wittur (2012). The goals of the reconstruction to the stoa of Amarynthos were to analyse the construction based on the available findings. The aim was to Figure out where the different elements were placed and how they connected together. That was also inevitable to confirm, whether an object actually belonged to the building or not.

a b c

Fig. 2. Reconstruction of the doric column. a) Fragments found and recorded through SfM were 3D printed in scale 1:10 and thus could be assembled. b) That was repeated with the virtual SfM-Models in 3D space. The column drum could be reconstructed. c) With the aid of secondary sources, the columns could be modelled and integrated to the doric order. (© O. Bruderer, ZHdK / ESAG).

The first step for the reconstruction model was to define the elements in situ. To that end the modelling process started with the replication of the excavated features through cubes, based on a georeferenced SfM models of the excavated structures and on precise CAD drawings. Thus, each building element was modelled with a separate volume and multiple elements combined into groups according to structure.

The second step was the completion of found elements not anymore in situ, often only fragmentary preserved. They were reconstructed and completed as necessary, either directly based on the SfM models or on reconstruction drawings or find illustrations – quite often a two-dimensional and orthographic drawings was a valuable assistance to 3D reconstruction. The reconstruction also helped to decide if an object had the right proportions and measurements to belong to the building.

The SfM models of the findings proved very helpful to assemble fragments, especially if that could not happen with the original findings (due to heavy weight, insufficient state of preservation or storage in different locations). Such was done with the fragments belonging to doric column drums (Fig. 2). Rather than assembling the virtual fragments virtually, it proved much more efficient to reproduce them via 3D printer and aligning the pieces physically. Some areas or elements of the building could not be completed solely by the findings of the excavation. Thus, comparable secondary sources from other excavations had to be consulted. These are commonly available as reports, articles etc. published by other excavation projects. The quality of these sources are accordingly substantial for the own reconstruction process. For the stoa of Amarynthos, the most relevant secondary source was the stoa in the sanctuary of Oropos, just across the South Euboean Gulf. Unfortunately, not all references were properly illustrated in the publication, making it necessary to rely on tourist photographs of the site. This example shows the importance of thorough documentation for any kind of further visualisation work.

To finally complete the reconstruction model, there are more often than not parts where one has only rather hypothetical secondary sources or that need some sort of „educated guesswork“. This last step to complete the reconstruction demands lots of caution and should influence the final model as little as possible.

For the whole reconstruction process, there were some crucial points considered. First, the whole reconstruction process was documented in detail (through text and screenshots). This allowed to be aware of the available evidence, the conclusion met whilst modelling and the knowledge gained. Second, every conclusion made was discussed with the experts of the team, the archaeologist Tobias Krapf and the architect & researcher Alexandra Tanner. She was also responsible for final 2D CAD plans, that contributed a lot to the final model.

Communication & Publication

At the end of the modelling process remains the question of how to communicate it to fellow researchers or to a wider public. The reconstruction model made for research purposes offers great possibilities for both. The model itself needs some manipulation, not only to show the final conclusion but also to make the research process transparent. For the model of the stoa in Amarynthos an interactive prototype was created using Adobe XD, to present the research model as part of an interactive publication (Fig. 3). The aim was to show the final model in comparison to the available sources and the decisions made, based on the reconstruction-argumentation-method as proposed by Grellert / Pfarr-Harfst (2019).

The interactive prototype allows the user to analyse the 3D model itself and access all the information involved. Much to the opposite of classical print publications, it offers not only a multilinear approach through interactivity, but it is also the model itself that gives orientation to the users. Integrating the SfM models of the finding into the virtual model allows direct comparison between find objects and hypothetical reconstruction.

Vorgeschlagene Lösung für die Rekonstruktion des Dachstuhls am Übergang zum Seitenflügel

Dachstuhl (Hinweise bei T1414)

Hölzerne Konstruktion, welche die Dachziegel trägt.

Holz überdauert als relativ unbeständiges Material nur unter optimalen Bedingungen die Jahrtausende zwischen der Antike bis in die heutige Zeit. Hinweise dazu finden sich daher oftmals bei Balkenlöchern in den Mauern oder anderen Vertiefungen in steinerner Architektur.
Auch bei der Stoa von Oropos finden sich solche Vertiefungen an der oberen Kante der Rückseite bei den Triglyphenelementen (hauptsächlich M1414). Diese weisen eine Distanz von etwa 108 cm auf und stammen wohl von den Dachsparren, also den schrägen Balken der Dachneigung.

Da dies die einzigen relevanten Hinweise sind, bleibt die gesamte Konstruktion des Dachstuhls bei der Oststoa von Amarynthos sehr hypothetisch.

Fig. 3. An interactive prototype allows the user to compare the reconstruction model with the findings. Text and illustrations explain the decisions made during the modelling process in detail. (© O. Bruderer, ZHdK / ESAG).

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Yeni Hammam: History in Graffiti

Catalogue of images found in plaster layers in an Ottoman bathhouse in Plovdiv

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Keywords: *Ottoman Bath—Hammam—Graffiti—Preservation—Architectural Heritage*

CHNT Reference: Toleva-Nowak, N. (2022). ‘Yeni Hammam: History in Graffiti’, in CHNT Editorial team (eds.) *Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020*. Heidelberg: Propylaeum.
doi:10.11588/propylaeum.1045.c14520

Historical Overview

Yeni Hammam is a 16th centrury Ottoman bath (the first mention in the Ottoman archives date back to 1541), located in the centre of Plovdiv, Bulgaria. It is a monument of culture of local importance and is one of the last two preserved Ottoman baths in the town. It functioned as a bath until 1990s. After a devastating fire in 2016, the building has been abandoned and heavily deteriorated, yet the fire revealed several layers of plaster and previously unknown decorations which clarified the history of the edifice.

Methodology

The author explores the history of the building by creating a complete catalogue of all the medieval graffiti and the murals from the Revival period, revealed in the plaster layers (Fig. 1), and thus puts the monument in national and international context referring not only to the eastern Ottoman bath tradition and construction, but also to the western decorative practices.

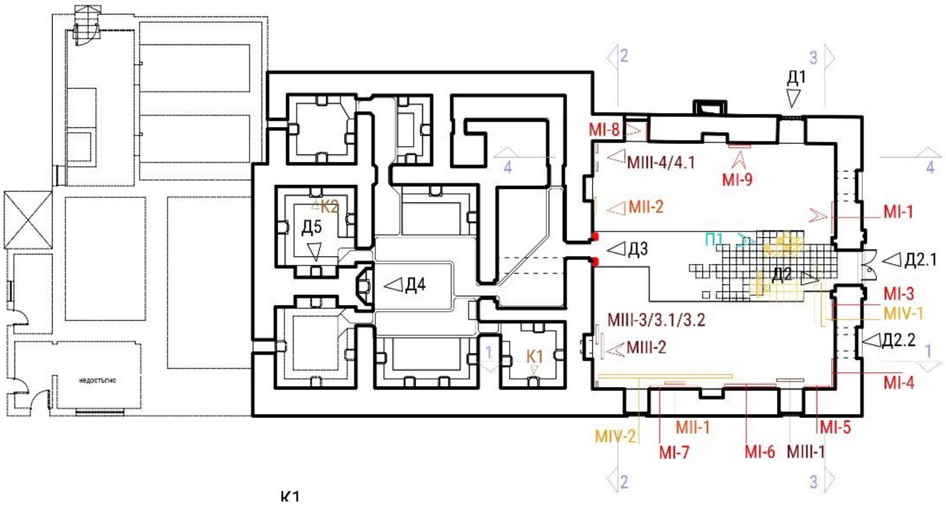

Fig. 1. Scheme of murals location (© Nina Toleva-Nowak).

Results

The analysis of the plaster layers revealed the following building periods:

First period (16th–17th century): The building was erected during 16th century (1530–1540), based on the Ottoman Tax Archives. It was located between the Turkish and the Jewish Quarters, tangent to one of the main commercial routes from Vienna to Constantinople. It functioned as a bath with few minor repairs. By the end of the XVI century the windows on the front façade were narrowed and new plaster layers were laid. Numerous graffiti drawings are also revealed in this layer (Fig. 1). The pigments used are in the dark range – cinnabar, ocher, black. The elements are inscribed in the plaster and vary in shape and size – letters from the alphabet, geometric shapes, scribbles, ships, warriors, and fish shoals (Fig. 2). They are in extremely fragile state, yet the author managed to document them all. Similar types of graffiti can be observed in medieval churches across Europe – Greece, Macedonia, France, Britain, etc.

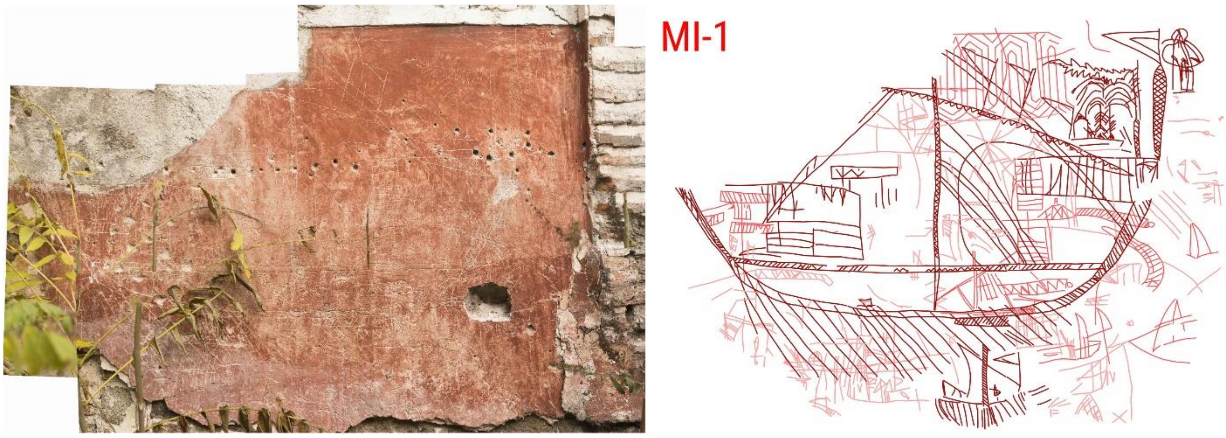

Fig. 2. Graffiti drawings (© Nina Toleva-Nowak).

Second period (18th – early 19th century): In the next plaster layer, traces of two bird images, most possibly peacocks, are found (Fig. 3). A similar technique of depicting tail and neck feathers is found in medieval manuscripts in both the Western and Eastern traditions (Manuscript Sac-ramentarium gelasianum, Psalter Netherlands, from Utrecht, 1290, Kalila and Dimna – 1310, Kitab Na't al- haya-wan wa-manafi'ihi, 13th century and Aja'ib al-makhluqat – The Miracles of Creation by Al-Qazwini, early 15th century.

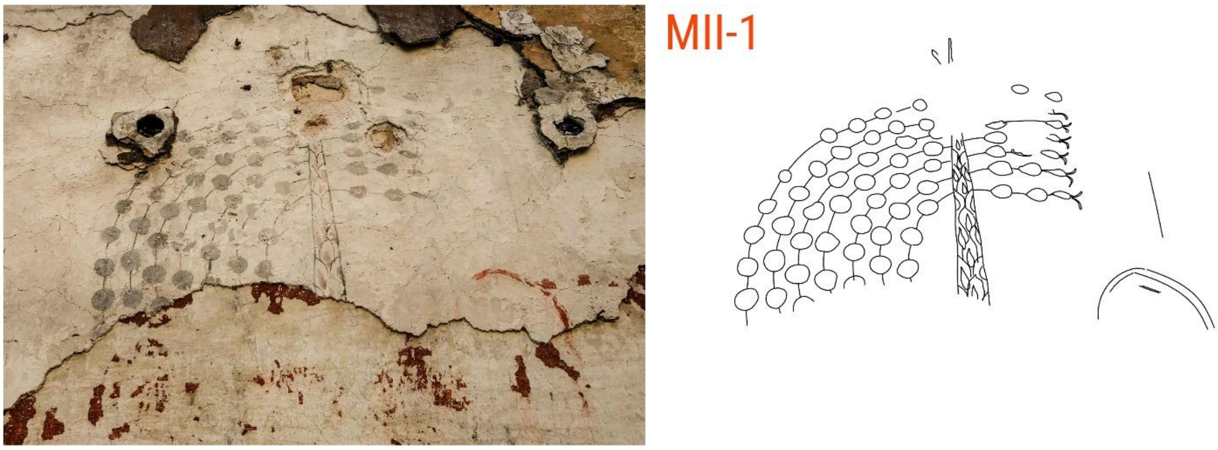

Fig. 3. Peacock detail (© Nina Toleva-Nowak).

Third period (1818 – 2nd third of the 19th century): After several earthquakes in the first third of the 19th century, the urban landscape of Plovdiv was heavily damaged. One of the most devastating earthquakes was the one from 1818 and it most probably led to the demolition of the original masonry dome and the need of quick construction of new wooden one, which can be spotted on later photos from 1892. The plaster layer is characterized by saturated, dark colors, executed entirely in the spirit of the frescoes from the early Bulgarian Revival (which are heavily influenced by the Western Baroque) – lavish hand-painted ornamentation with the rhythmic demarcation of the mural panels (traced throughout the height of the dressing room), reinforced with black ribbons and lines in Turkish blue and ultramarine. These murals are severely damaged and can be traced only in a few fragments (Fig. 4). The author is currently working on a restoration project based on the documented elements.

Fig. 4. Early Revival murals (© Nina Toleva-Nowak).

Fourth period (2nd third of the 19th century – 1928): The next plaster layer is characterized by bright, colorful chromatics (white, Turkish blue, yellow, black) and remnants of painted architectural elements – columns, railings, vases. The style of the murals is typical for the Mature Revival (the second third of the 19th century). Unlike the previous plaster layer, here the ornamentation develops in height – the preserved fragments are at the level of the second floor, around the windows. Given the classical proportions of the painted columns (Fig. 5), and given the growing population of the city and the need for more infrastructure, probably in this period a wooden gallery in the locker room appeared, forming a second floor. Its presence is documented in the photographs archived in National Institute of Immovable Cultural Heritage during survey from 1980s. The window openings on the second level were probably drilled in the stone wall during that period. Unfortunately, this plaster layer is heavily damaged and its reconstruction is becoming more and more challenging.

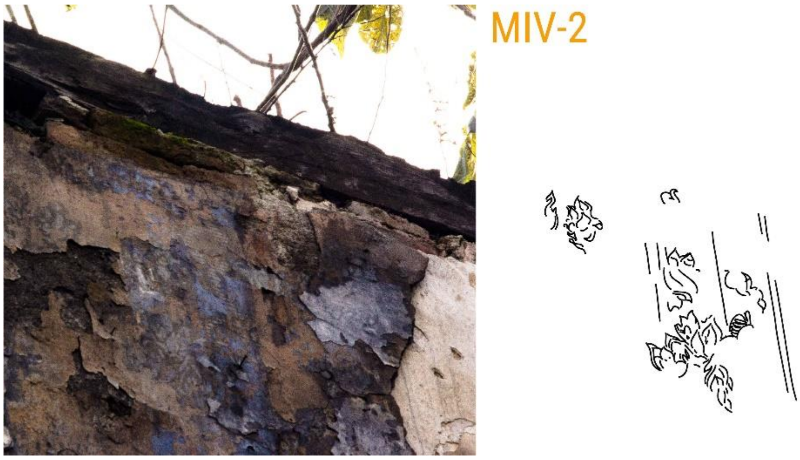

Fig. 5. Late Revival murals (© Nina Toleva-Nowak) remnants of column with decoration.

Fifth period (1928–1945): In 1928 another devastating earthquake had taken place and the wooden roof was destroyed for a second time. Evidence for this we find by comparing two photos of the building – the first one from 1892 clearly showing the roof of the bathroom, as well as the Tash Kopryu mosque with its minaret, destroyed in 1928 during the great Chirpan earthquake, and a second one photo from 1930s, which clearly shows the major change in the slope of the roof and its overall morphology. After the final reconstruction, the roof remained classic pitched roof with small partial segment timber dome hidden in it. In that period, after the reconstruction, the walls were treated with roller stencils and decorative floor ceramic tiles were installed.

Sixth period (1945–1989): The window openings of the central facade were finally closed and ceramic tiles on the floor in the dressing room were laid. Some of the stone sinks have been replaced by cast concrete mosaic elements. Ceramic tiles (uncalibrated) have been laid on the walls and the plinths. The higher part of the walls, along with the domes, have been treated with oil-based paint. The holes made for the wood-burning stoves used for heating indicated that the hypocaust system may no longer have functioned.

Seventh period (1989–2016): The bathroom retained its authentic function until the end of the 1980s, and was subsequently turned into a shop and warehouse for solid wood furniture. To this last function we can refer the final closing of the secondary entrance of the north-west wall of the dressing room. On February 18 - 19, 2016, a fire burned the most representative part – the dressing room with a wooden sloping roof and a segmental dome, the staircase to the gallery on the second level. The bathroom finally closes its doors and remains in high-risk of self-destruction due to weather conditions, threatening to lose the memory of the building and the traces of Ottoman public baths in Plovdiv. By 2022, no strengthening of the structure of the walls or the domes were implemented and the facility remains in extremely poor condition.

Conclusion

The study of the immovable cultural heritage of local significance revealed the rich and full of twists history of the building. Placed in a Balkan and European context, it does not lose its value, on the contrary – it is a witness to a unique amalgam of Eastern architectural and urban influences and Western European techniques of monumental synthesis of arts. The evolution of the decoration in the most representative room (the dressing room), and the multiple layers with their specifics (graffiti drawings, stylized images of birds, traditional Revival decorations, techniques of applying patterns with a roller, etc.) prove that with such buildings there is a need for a strict research methodology so that each monument is examined in the necessary depth and context, in order to prevent the loss of valuable information. The author is currently working on a reconstruction of the decoration, which will be presented in the future.

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Temporal Visualization and Data Analysis of Archaeological Finds

Case FindSampo

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Keywords: *Visualization—Semantic Web—Archaeological Finds—Temporal—Timeline*

CHNT Reference: Anafi, B., Koho, M., and Hyvönen, E. (2022). 'Temporal Visualization and Data Analysis of Archaeological Finds. Case: FindSampo', in Börner, W., Rohland, H., Kral-Börner, C. and Karner, L. (eds.) *Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020*. Heidelberg: Propylaeum.
doi:10.11588/propylaeum.1045.c14521

Introduction

Cultural Heritage (CH) collections, data, and artefacts used to be available mainly in galleries, libraries, archives, and museums (GLAM). Nowadays CH data is available also online, and it can be searched, analysed, and presented using various methods and visualizations tools. However, many of these methods do not take adequate advantage of the nature of CH data. Even when the CH data dimensions are exploited, the choices of visualization sometimes fall short.

This paper concerns the semantic portal part of the Finnish archaeological finds framework FindSampo (Hassanzadeh et al., 2020), and especially its timeline-based visualisation application for studying archaeological artefacts and their categories in time. FindSampo has been created as part of the Finnish Archaeological Finds Recording Linked Open Database (SuALT) project[2], which is a response to the rapidly growing popularity of metal detecting in Finland. The project aims to develop digital web services to cater for archaeological finds made by members of the public, especially metal detectorists (Thomas et al., 2018). The goal of the FindSampo framework is to 1) support the metal detectorist community in learning archaeology and their hobby, 2) to help the Finnish Heritage Agency in recording the finds in their databases, and 3) to support Digital Humanities (DH) researchers by helping them to study the data with data-analytic tools. This paper provides an insight and a possible solution into one of the research questions posed by our collaborating archaeologists: how to visualize the temporal spread of finds on a timeline, filtered by their characteristics, such as object type, material, timing, and geographical location?

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[1] http://seco.cs.aalto.fi

[2] http://seco.cs.aalto.fi/projects/sualt/

Sampo Platform for Studying Archaeological Finds

FindSampo portal is a new member of the "Sampo" series[3] of Linked Open Data (LOD) services and semantic portals, based on a national Semantic Web infrastructure. The prototype includes a user-centric faceted search combined seamlessly with data-analytics tools for visualising the filtered data on a table, a timeline chart, and on maps. There is also an option to export the results in CSV form for further analysis in external tools. The underlying LOD service is available to data-analysis using tools such as YASGUI for SPARQL querying (Rietweld and Hoekstra, 2017) or Jupyter[4] and Google Colab[5] for Python scripting.

In the design of the FindSampo portal, the technologies were chosen based on technical efficiency, user needs, and the nature of the data—especially the spatio-temporal dimension of the data. The prototype is based on the Sampo model[6], the Sampo-UI[7] framework, and several third-party libraries for, e.g., visualisations. The portal is a single-page application, and therefore page reloading is not needed when navigating around. This enables the user to use it more efficiently in places where the Internet connection is slow. FindSampo is based on modern JavaScript libraries, such as React[8], Redux[9], Material UI[10], and Sass[11] on the client side. The server is implemented using NodeJS[12] and ExpressJS[13] to enable a lightweight interaction with external services.

The portal provides several interactive linked views to the underlying data that deal with the find data (using keywords), geography (maps), timelines, and their interrelations. It caters for the spatial dimension of the data by providing two map views: a point map and heatmap. Therein the user can see the geographical distribution of the finds and learn about them.

FindSampo uses archaeological find collection data from the Finnish Heritage Agency as source data. The data contains approximately 3000 finds from Finland, ranging temporally from 8000 BC to 2000 AD, in a structured format, with each find described in terms of 50 metadata fields. The source data is converted into RDF format and published as LOD, which is used in the portal directly from a public SPARQL endpoint. FindSampo utilises Semantic Web and emerging Web technologies to provide a platform for studying archaeological finds. Semantic Web technologies[14], such as ontologies (Staab and Studer, 2009), are used for harmonizing the data within Finnish archaeological data sources and for establishing interoperability with international archaeological resources. For this purpose, the Finnish ontologies were aligned with, e.g., the Art and Architecture Thesaurus (AAT)[15] of the Getty Research Center, as suggested in the pan-European ARIADNEPlus initiative[16].

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[3] For a list of Sampo portals, see https://seco.cs.aalto.fi/applications/sampo/.

[4] Jupyter: https://jupyter.org/

[5] Google Colab: https://colab.research.google.com/

[6] Sampo: https://en.wikipedia.org/wiki/Sampo

[7] Sampo-UI: https://seco.cs.aalto.fi/tools/sampo-ui/

[8] React: https://reactjs.org

[9] Redux: https://redux.js.org

[10] Material UI: https://material-ui.com

[11] Sass: https://sass-lang.com

[12] NodeJS: https://nodejs.org

[13] ExpressJS: https://expressjs.com

[14] Semantic Web standards: https://www.w3.org/standards/semanticweb/

[15] https://www.getty.edu/research/tools/vocabularies/aat/

[16] ARIADNEPlus: https://ariadne-infrastructure.eu/

Visualizing Archaeological Finds on a Timeline

For the temporal dimension, the period associated with each find is converted to a discrete time span to accommodate all finds. The portal features a novel interactive timeline chart, where the user can easily see the distribution of the finds on a timeline. There the timeline segments represent finds which are grouped by the provinces of Finland they were found and assigned colours for conspicuity and differentiation. This provides the user with a new kind of perspective to the spatial distribution of the finds in time.

The timeline chart was implemented using the Timelines chart library[17] that was created by Vasco Asturiano[18]. It is made up of groups of finds layered one above the other. Each group contains layers of finds. It also features an interactive interface and a timeline brush at the bottom which users can use to explore the finds either by zooming (dragging) on the chart directly or on the timeline brush. Users can also click on a find to learn more about the find on its own landing page. This library was chosen for the implementation because its evaluation suggests that it can facilitate visualisation design principles, such as serendipity, generosity, and criticality (Windhager et al., 2019). It is also capable of showing other dimensions of the data in addition to the temporal dimension by grouping the data using that dimension. For example, the finds shown in Figure 1 are grouped by the provinces of Finland they were found.

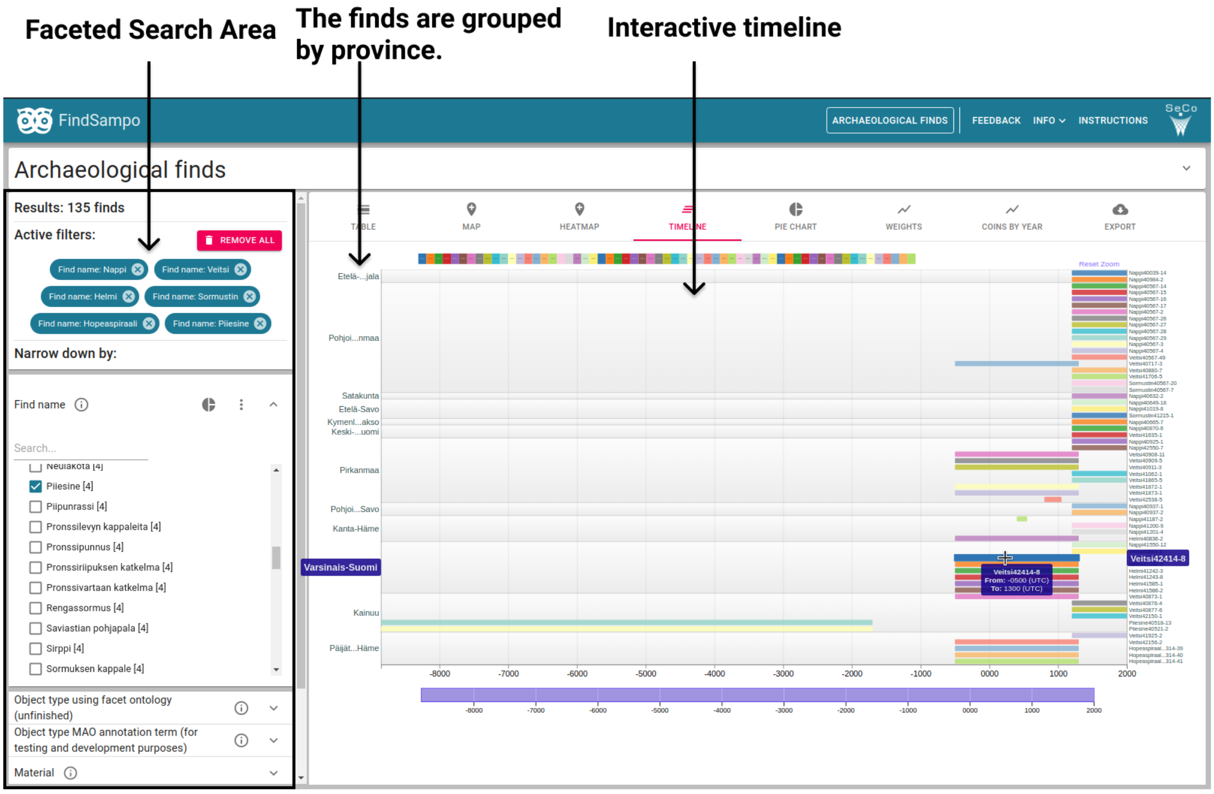

Fig. 1. The novel timeline visualization in the FindSampo portal's user interface, in which the faceted search filters the result set to be visualized. (© Authors).

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[17] Timelines-chart: https://github.com/vasturiano/timelines-chart

[18] Vasco Asturiano: https://bl.ocks.org/vasturiano/ded69192b8269a78d2d97e24211e64e0

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Concerns over Radiation-Induced Side Effects in Cultural Heritage

A Common Issue for Scientific Communities Using Radiation for Characterization or Preservation of Cultural Heritage

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Keywords: *Cultural Heritage—Radiation—Side Effects—Analysis—Preservation*

CHNT Reference: Cortella, L. et al. (2022). 'Concerns over Radiation-Induced Side Effects in Cultural Heritage', in Börner, W., Rohland, H., Kral-Börner, C. and Karner, L. (eds.) *Proceedings of the 25th International Conference on Cultural Heritage and New Technologies, held online, November 2020.* Heidelberg: Propylaeum.
doi:10.11588/propylaeum.1045.c14522

Introduction

Electrons, X-rays, neutrons, ions and gamma rays are radiations commonly used in imaging and spectroscopy to provide information about materials in archaeological, paleontological, historic or artistic objects, as illustrated in Figure 1 (a, b) (IAEA, 2011). Gamma and electron irradiation is also widely used for biocide treatments of organic artefacts (see Fig. 2a), and in the consolidation of weakened objects with radio-curable resins (IAEA, 2017).

Because of the unique value of cultural heritage objects and the risk of loss of critical analytical information, any investigation or treatment must mitigate side effects induced by radiation. Therefore, knowledge about potential side effects and underlying physico-chemical mechanisms is key.

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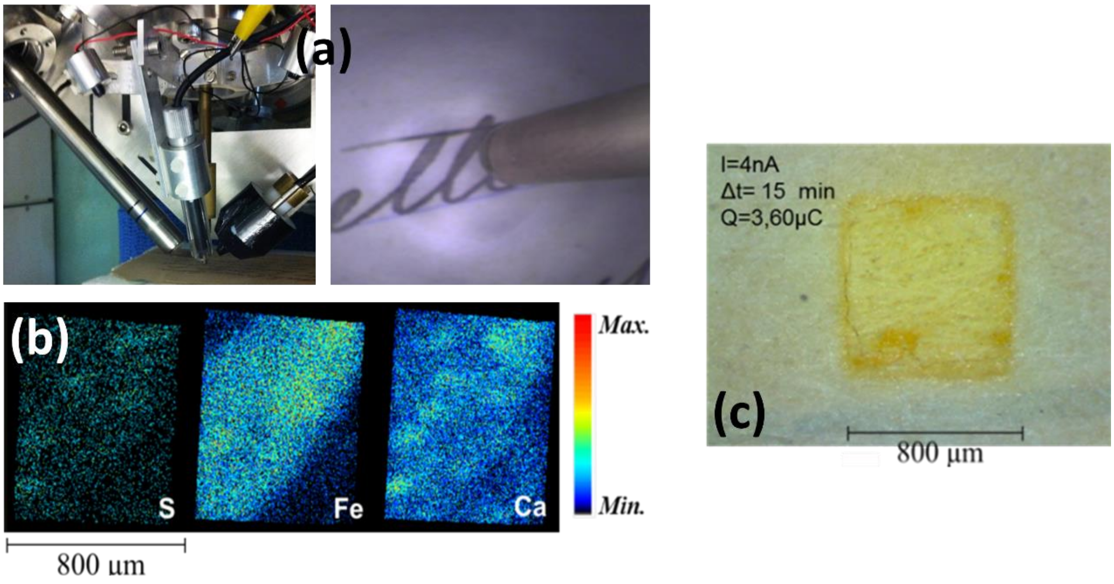

Fig. 1. External ion beam set-up at C2TN. 2MeV proton beam is used to measure iron gall ink in an ancient manuscript (a). The beam can raster the surface and 2D elemental maps from PIXE spectra can be obtained (b). Irreversible damage (degradation of cellulose chains and oxidation processes) induced by proton beam on a white paper sample using a very high intensity beam; in extreme cases the paper will completely collapse structurally (c). (© C2TN).

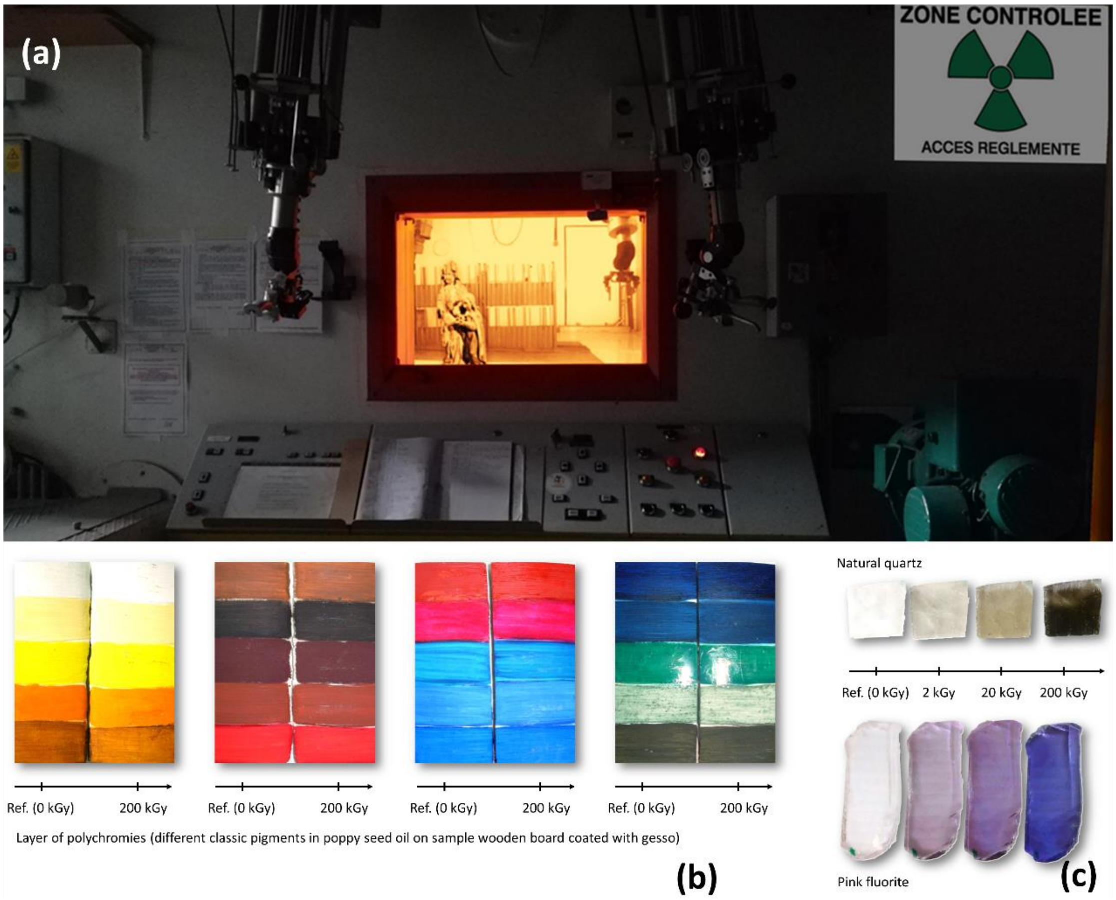

Fig. 2. Insect eradication in ARC-Nucléart of a polychrome wooden sculpture ("Education of the Virgin", 17th c., Chateau-Chalon, France) (a). 500 Gy is the minimum gamma irradiation dose. Possible changes of color is one the main issues to be taken into account but classical polychrome layer are generally very stable with irradiation (b), in contrast to some transparent materials that can be used as ornament in artwork (c). (© ARC-Nucléart).

Knowledge of Side Effects

While there is good general understanding of the effects of irradiation on materials in other fields (e.g. food industry, nuclear or medical industries), targeted studies to explore the fundamentals of irradiation side effects on cultural heritage materials and objects are still needed (Bertrand et al., 2015). The diversity of materials encountered in cultural heritage is vast and objects are often of heterogeneous composition on several scales, always requiring more applied and fundamental research. The main physico-chemical changes observed in the below examples show the importance of such research:

- Radiation easily tints transparent materials, in some cases even at doses below 1 kGy, due to trapping of electrons in the vicinity of impurities (Fig. 2c). Such behaviour often does not affect visually opaque materials, such as polychrome layers (Fig. 1b).
- At higher doses, broken bonds, cross-linking and temperature-induced effects can modify important material properties and affect mechanical integrity (see Fig. 1c). With heavy or very energetic particles, atoms may be knocked out, giving rise to vacancies and molecular defects.
- Radiation-induced radicals can trigger undesirable chemical change, such as oxidation. It can lead to colour changes or surface erosion, and induce long-term autocatalytic degradation mechanisms.

Risk Analysis

The consequence of side effects may not only affect the characteristics and behaviour of the heritage material or object; but there is a risk that they distort immediate or future analyses. Therefore, researchers and conservators must together weigh the expected benefits of exposure against possible drawbacks before any treatment or investigation of a cultural heritage artefact is carried out. For example, considering the radiation-based treatment of objects, the range of irradiation dose used for fungicidal treatments (typically 5 to 10 kGy) entails the possibility of generating minimal effects in somewhat sensitive materials like paper. Notwithstanding this slight risk, the reliability and ease of implementation of these methods – if equipment is available – make their application a viable option. The question “is the radiation treatment better or worse than alternatives, including doing nothing?” must always be asked.

Mitigation and optimization.

To avoid over-exposure, optimization and careful control of all parameters is crucially important. An ALARA (As Low As Reasonably Achievable) approach has been proposed regarding the minimum dose, dose rate and the time of exposure (IAEA, 2018). Good practices include dosimetry (simulations and measurements) and should take into account the radiation interaction parameters of the target materials or surrounding media. If a large object is exposed, or if important gradients of dose are expected, mapping may provide more precision. For sensitive materials, when possible, real-time monitoring of relevant changes during experiments allows stopping experiments at the first sign of concern.

Controlling the environmental parameters and atmosphere (inert gas, vacuum, low temperature, etc.) can effectively mitigate some adverse effects like oxidation. Humidity control can be beneficial, for instance to avoid secondary reactions linked to water radiolysis. Experimentalists training and increasing awareness is of paramount importance and has been supported by IAEA (Bertrand et al., 2015), which dedicated Technical Meetings in Paris (2015), Amsterdam (2017) and Zagreb (2018).

Documentation.

Documentation is a crucial pillar of the whole cultural heritage field. It must include documenting condition of exposure to radiation. Dosimetry data can be supplemented by experimental parameter monitoring. Detectable change should be better investigated, quantified and documented. A digital exposure passport reporting the main radiation parameters experienced by an object or a research sample is currently under development.

Conclusion

Scientists involved in cultural heritage research and conservation need radiation techniques for a variety of applications. Special care is vital in order to avoid radiation-induced side effects that may affect the material characteristics and (future) behaviour of cultural heritage objects. Understanding such effects is a prerequisite both for specialists working on material analysis and for those involved in the treatment of cultural heritage, and risk analysis must be undertaken before exposure. This can only be supported by dedicated research programs.

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