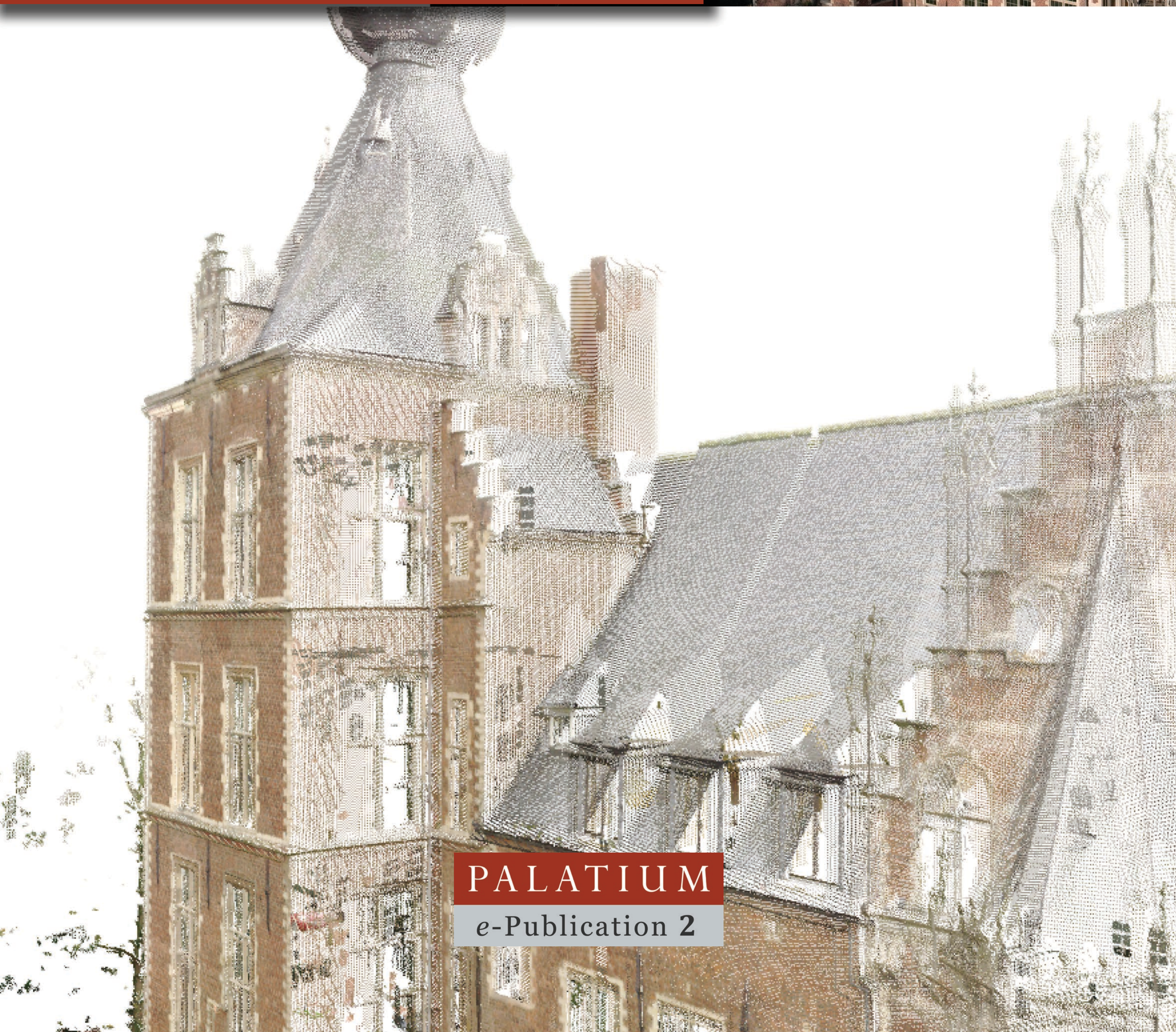
Virtual Palaces, Part I
Digitizing and Modelling Palaces

Edited by

Pieter Martens



PALATIUM

e-Publication 2

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Edited by
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With the assistance of
Heike Messemer

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Cover image: Castle of Arenberg in Heverlee (Leuven). Photograph (2011) and 3D laser scanning point cloud model (2015). © RLICC-ARCHDOC, Mario Santana, Bill Blake, Rand Eppich.

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Preface

Krista De Jonge, PALATIUM Chair (KU Leuven – University of Leuven, Belgium)

Founded in 2010 and financed by the European Science Foundation, the PALATIUM research networking programme aimed at creating a common forum for research on the late medieval and early modern European court residence or palace *(palatium)* in a multi- and trans-disciplinary perspective (www.courtresidences.eu). In the broad and varied field of court studies, PALATIUM's focus on the court residence stands out as a main defining characteristic, distinguishing it clearly from similar initiatives in Europe. Fourteen research institutions from eleven European countries supported this initiative during its five-year run. Thanks are due here to all member organisations who stood behind this 'network funded by a consortium' and to its 'parent company', the European Science Foundation; but also to KU Leuven – University of Leuven on the one hand and the Ludwig-Maximilians-Universität München on the other, the hosts of the double event, which is reflected in the volumes no. 2 and 3 of the PALATIUM *e*-Publications.

Through its methodological workshops, PALATIUM meant to attract specialists in court studies (historians, art historians) ready to work with architectural historians in an interdisciplinary perspective, and to help develop new methods or tools, with the specific aim of developing user-friendly ways of presenting the research in this field to the larger community.

The collection of essays presented in the volumes no. 2 and 3 of the PALATIUM *e*-Publications, resulting from the Leuven meeting of 18-19 November 2011 and the Munich meeting of 13-14 April 2012, is dedicated to the reconstruction of the palace as virtual heritage. Over the past decades, digital reconstructions have proven their usefulness in visualizing palaces but also in clarifying data and research results (e.g. construction phases, ceremonial use). PALATIUM's interest focused on the methodological implications of these increasingly sophisticated tools, i.e. the interface where architectural history and digital technique must meet and interact. Within this perspective, Part I, *Digitizing and Modelling Palaces* (Leuven) focused on the digital recording and virtual modelling of historic buildings in their actual state, and the related methodological problems, while Part II, *Lost Palaces and their Afterlife. Virtual Reconstruction between Science and Media* (Munich) focused on virtual reconstructions of 'lost' buildings and their role in research on court residences. Neither of these volumes has any pretensions to covering the whole subject, but rather aims at raising awareness – on the historian of art and architecture's side – of the added value such digital tools can bring to the research on residences, and at setting out the necessary boundary markers – on the digital expert's side – guaranteeing the scientific usefulness of digital reconstruction. As the second and third volumes in PALATIUM's series of *e*-publications, we hope that they will easily reach their audience.

Introduction

Pieter Martens (KU Leuven & Université catholique de Louvain, Belgium)

Virtual Palaces

The rapid rise in new digital technologies has revolutionized the ways in which historic buildings – such as palaces – are being recorded, digitized and virtualized. These new techniques offer unprecedented opportunities for architectural historians, but also lead to new problems and challenges. A first major challenge is to ensure the scientific validity of a virtual building. Here the reliability and verifiability of the information that is used to make a digital model is of vital importance. This applies not just to the tools and technologies that are used to survey a building in its actual state, but also to the methods that are employed to make a virtual reconstruction of a lost building (or a former state of an extant building). A second issue concerns the role of virtual buildings as research instruments in their own right. There is no doubt that digital models of court residences can be very useful, not just for communicating research results to the wider public, but also as genuine research tools that help visualize and clarify working hypotheses, for example about construction phases or the ceremonial use of the spaces. Yet the potential role of digital models as research tools in this domain has not been fully explored.

These two related methodological issues were the subject of two consecutive PALATIUM workshops held in Leuven (Belgium) in November 2011 and in Munich (Germany) in April 2012. The Leuven workshop, *Part I. Digitizing and Modelling Palaces*, focused on the surveying, recording, digitizing, and modelling of extant palaces in their actual state. It also looked at the potential role of the resulting digital models as research instruments and as vehicles for the preservation and dissemination of knowledge. The Munich workshop, *Part II. Lost Palaces and their Afterlife. Virtual Reconstruction between Science and Media*, dealt with virtual reconstructions of 'lost' palaces (including 'lost' states of still existing palaces). It explored different methods and technologies for the visualization of non-extant buildings and examined the utility of such reconstructions as tools for research and communication.

Part I. Digitizing and Modelling Palaces

The PALATIUM workshop *Virtual Palaces, Part I. Digitizing and Modelling Palaces* was held in Leuven on 18–19 November 2011. It was organized by Krista De Jonge (KU Leuven, PALATIUM Chair), Pieter Martens (KU Leuven, PALATIUM Coordinator) and Mario Santana Quintero (KU Leuven and Carleton University, Canada), in collaboration with the Raymond Lemaire International Centre for Conservation (RLICC) of the University of Leuven.

The workshop took place in a suitable venue: the sixteenth-century Castle of Arenberg in Heverlee near Leuven. Now the seat of the Department of Architecture, this former court residence once belonged to the Dukes of Croÿ (who rose to prominence in the fifteenth and sixteenth century, especially under Emperor Charles V and King Philip II of Spain) and is itself the object of ongoing historical research and digital modelling.

As a preamble to the workshop a practical seminar on digital recording methods was organized by the RLICC. It included a demonstration of different 3D laser scanning techniques in the courtyard of the Arenberg Castle and a session in which the RLICC students presented the results of their ARCHDOC (Architectural Heritage Documentation for Conservation) Workshop. Thanks are due to the ARCHDOC team, to the Raymond Lemaire International Centre for Conservation, and especially to Mario Santana for organizing this instructive methodological seminar in conjunction with the PALATIUM workshop.

The workshop itself provided a platform for scholars to present and discuss different approaches in the effective use of digital tools to make virtual models of existing palaces. Because of its methodological nature, the workshop did not strictly limit itself to late medieval and early modern Europe, but embraced also case studies that fall outside the chronological and geographical boundaries of the PALATIUM programme.

The workshop opened with a presentation of the results of ten years of ongoing work on the Castle of Arenberg by Bill Blake (ICOMOS UK), Björn Van Genechten (University College St Lieven, KU Leuven) and Krista De Jonge (KU Leuven). The other keynote lectures, by Ana Almagro Vidal (Historic Heritage Conservation Department, Fundación Caja Madrid), on the Islamic palaces of Al-Andalus, and by Rand Eppich (Tecnalia Research & Innovation), on the future of 3D tools for capturing, modelling and documenting cultural heritage, provided further points of reference on the subject.

Various technological, methodological and theoretical aspects of virtual models and virtual reconstructions were then examined through fifteen case studies which focused on castles, palaces and residences from different periods and different regions, including Budapest, Monza, Potlogi, Sintra, Valladolid, Venice, Versailles and Vienna, as well as Jordan and Bengal. Most of these case studies were multidisciplinary in nature and the work of multiple authors combining an expertise in digital surveying and modelling techniques with an expertise in architectural history. Another common characteristic of these case studies is that they use digital models first and foremost as tools for scientific research; this implies that the 'look' of the virtual model (which may range from a basic schematic outline to the highest degree of realism) is not a goal in itself but subordinate to its usability as an instrument to visualize and test hypotheses.

The five papers collected in this volume are a selection of the papers presented at the workshop. They have been edited by Pieter Martens with the assistance of Heike Messemer (design and production) and Adam & Alisa Fowler (proofreading).

In the first paper Noémie Renaudin, Bertrand Rondot and Livio De Luca present their virtual reconstruction of the Petit Trianon in Versailles. A remarkable aspect of this case study is that it models not only the architecture of the building, but also its original pieces of furniture and other furnishings, which makes it possible to visualize the original appearance of the rooms at different moments in time. It also illustrates how a rigorous scientific approach can be combined with a highly realistic model destined for the wider public.

The paper of Daniela Oreni, Raffaella Brumana and Branka Cuca focuses on their 3D survey of the eighteenth-century Villa Reale in Monza. They pay particular attention to the vaults of the main rooms of the Villa and demonstrate how their digital model can help understand how these cloister vaults were originally designed and constructed.

In the third paper Anca Bratuleanu, Stefano D'Avino and Giovanni Mataloni present their ongoing research on the palace of Potlogi in southern Romania. Built in 1698 this palace played a key role in the development of residential architecture in Walachia. Their digital survey and 3D model allows this important historical building to be studied remotely and can also be used as an instrument for (virtual) restoration.

The paper of Md Mizanur Rashid and Hafizur Rahaman deals with the eighth-century Buddhist monastery of Sompur Mahavihara in Paharpur, Bangladesh. In this case the problem of modelling and virtual reconstruction is particularly difficult because only fragmentary ruins remain, without any other documentary evidence. This contribution shows that even in such circumstances a rudimentary digital model can be a useful scientific instrument, not so much to present a complete reconstruction of the lost monument, but rather to offer and compare different hypotheses.

The final paper, by João Neto, Maria Neto and Ricardo Silva, concentrates on the Monserrate Palace in Sintra, Portugal. It illustrates how a high-quality digital model of a historic building can be used in multimedia applications aimed at wider public, such as games. Emphasizing the potential of virtual models as didactic tools, they show how the experience of cultural tourism might be enhanced by enabling people to pay a virtual visit to the palace.

Together these five case studies offer a broad spectrum of possible uses for 'virtual palaces'. Indeed the different types of models presented here are as varied as the palaces themselves. Naturally this modest collection of papers does not pretend to cover the entire subject. Its purpose is merely to illustrate the potential of digital modelling for scientific research on extant historical palaces and similar buildings, while at the same time raising consciousness about the methodological difficulties involved. To better appreciate the wide range of possibilities of virtual models of residential architecture, the reader is advised to consult also the papers from the Munich workshop, which are collected in the second *Virtual Palaces* volume.

3D Virtual Reconstruction and Visualization of the Petit Trianon in Versailles

Noémie Renaudin (UMR CNRS/MCC 3495 MAP-Gamsau, France)

Bertrand Rondot (Etablissement Public du musée et du domaine national de Versailles, France)

Livio De Luca (UMR CNRS/MCC 3495 MAP-Gamsau, France)

It is difficult to grasp the complex history of the successive changes of the furnishings and layout of the Petit Trianon. Our ongoing project addresses this challenge. Based on 3D digitizing, high photorealistic rendering, real-time visualization and spatio-temporal data structuring, our approach provides more than a straightforward 3D model of the rooms: it ensures that the contents of the rooms are not fixed in their current state, but enhanced on the basis of additional perspectives. The refurnished virtual rooms are, paradoxically, more realistic. Freed from the constraints imposed by visitor traffic and security, they are presented not in their existing fragmentary state, but as a completed whole. Our data structuring method also enables the user to explore the consecutive changes of the furnishings over time (integrating furniture which today is conserved in different museums worldwide) and thus provides a dynamic vision of the Petit Trianon's spaces. The current project focuses on the 3D reconstruction and virtual visualization of the rooms and their furnishings in their current state.

Today it is possible to discover a historic site not just in its current state but through its successive occupants and developments over time. The château of the Petit Trianon is above all associated with Marie Antoinette (1755–1793), whose time is still predominant in the eyes of most visitors. But this place witnessed different periods and different people with different tastes, and the corresponding changes to its furnishing also deserve to be revealed to the public.

The Petit Trianon was inaugurated by Louis XV and Madame Du Barry in 1768. In 1774 the new King Louis XVI gave it to his Queen Marie Antoinette, who made it her favourite place. She first devoted herself to landscaping and in the 1780s began to renew its furniture. Emptied during the Revolution, the château was finally taken over by Napoleon in 1805 to house his sister Pauline Bonaparte, Princess Borghese. But it was for the Empress Marie Louise, married in 1810, that most of the new pieces of furniture were provided. During the Restoration the place remained uninhabited, and afterwards the furniture supplied under the Empire was completed in the new romantic taste. The fall of the July Monarchy in 1848 led to the abandonment of the Petit Trianon as a residence and it was during the Second Empire, in 1867, that the Empress Eugenie installed there a museum dedicated to the tutelary figure of the place, Marie Antoinette.

This complex history is difficult to grasp by the public. The current presentation focuses on the time of Marie Antoinette on the first floor and mentions the succession of its various occupants in the attic. Thanks to the 3D digital representation, the château can be virtually refurnished with great accuracy and in accordance with successive historical states. The virtual tours of the furnished rooms allow one to discover the varying tastes of its occupants at different times.

Objectives of the Model

The model is more than a mere transposition of the rooms into 3D views. The digital model allows to represent not just the collections that are actually visible on site, but to further enrich this content along complementary axes.

First, the virtual refurnishing is, paradoxically, more realistic. The furniture finds its natural location and the virtual visitor can move freely through these spaces, without the constraints of safety regulations or the flow passages reserved for groups. Moreover, when certain elements of a set (for example, a set of chairs) are lost, the set can be virtually completed by duplicating a 3D model of the preserved element.

Second, groups of objects that have since been scattered around the world are reunited virtually. Some pieces of furniture and other objects are now preserved in different museums abroad. With the exception of a flat desk made for Louis XVI (which is now in the J. Paul Getty Museum in Los Angeles and was temporarily loaned to the Petit Trianon) it is usually impossible to bring these objects back, but they can be digitized and virtually replaced in the room for which they were conceived. For example, a mechanical table preserved in Waddesdon Manor (Great Britain) was among the first pieces of furniture ordered by Marie Antoinette for the Petit Trianon; its return is virtually possible with the 3D digital representation.

Third, broken-up furniture can be reassembled virtually. A modified piece of furniture can be returned to its original state by modelling the several scattered elements. This is the case of a table with sliding top, belonging to Marie Antoinette: only its top is preserved (in the Victoria and Albert Museum in London) but its base type is known from other copies.

The digital representation must also be able to deal with the chronology of consecutive furnishings in a dynamic vision of the spaces. Thus the bedroom of Marie Antoinette, originally used by Madame Du Barry, was later occupied by Pauline Borghese, then by the Empress Marie Louise, and finally by the Duchess of Orleans. Some pieces of furniture were retained from one period to the next, while others were replaced by more modern furniture. The virtual visitor can view successive furnishings, according to chosen chronological marks, and corresponding to different inventories: a first state in 1780 (after the first orders placed by Marie Antoinette and before the full refurnishing of her apartment in 1787–88); a second state in 1811 (corresponding to the inventory drawn up by the Empress Marie Louise in 1810 and completed in the following year); and a third state in 1839 (corresponding to the inventory drawn up by the Duchess of Orleans).

Data Acquisition and 3D Reconstruction

The main idea of this work is to provide a virtual tour of these furnishings coupled with an interactive database. It presents not only the technical and historical information of each object or piece of furniture, but also allows to manipulate each element in space, so that the user can see moveable parts in different states (for example by virtually opening a writing table's desktop or drawer) and discover hidden details (such as inventory numbers marked under the seats). The basis of this project is therefore the integration of the techniques of digitizing, geometric reconstruction and 3D visualization.

3D Digitizing of Rooms

The interior spaces of the rooms are digitized using a 3D phase-shift laser that can acquire up to 100,000 coordinates per second. Point clouds resulting from this acquisition are assembled to make a precise geometric model of the existing spaces (fig. 1). In addition, a high-definition photography campaign has recorded the surfaces' visual appearance (fig. 2).

Fig. 1 Point cloud obtained by laser scanning of room.

Fig. 2 High-definition photographic acquisition.

The 3D reconstruction of the rooms is based on an interactive geometrical modelling starting from relevant profiles extracted from the point cloud. The linking of the geometric model of the spaces with all the photographs allows one to reconstruct the visual appearance of the surfaces by projecting textures taken directly from these photographs (oriented on the 3D model by resection).

3D Digitizing of Furniture

Apart from surveying the architectural volumes, the project comprises the digitizing of figural objects and pieces of furniture that are now preserved in different places. The geometry and texture of 91 elements, located in France and in the United Kingdom, have actually been acquired. Other campaigns are being organized in the United States. The 3D digitizing was performed with a triangulation laser which acquires shapes with millimetric precision and a high-definition camera. Different 3D reconstruction techniques (automatic meshing, image-based modelling, reconstruction by parametric surfaces, and so on) are implemented in function of the morphological complexity of the object and the nature of its materials.

- **Laser-based modelling**. In the case of the restitution of sculpted objects such as busts, point clouds were automatically obtained by common meshing algorithms. Meshes of resulting models contained between 100,000 and 400,000 polygons, providing a very accurate reproduction of the complex geometry of the object. In order to enhance the visual aspect of the objects, an 'ambient occlusion' rendering was realized and its result was assigned to each vertex of the mesh (fig. 3).

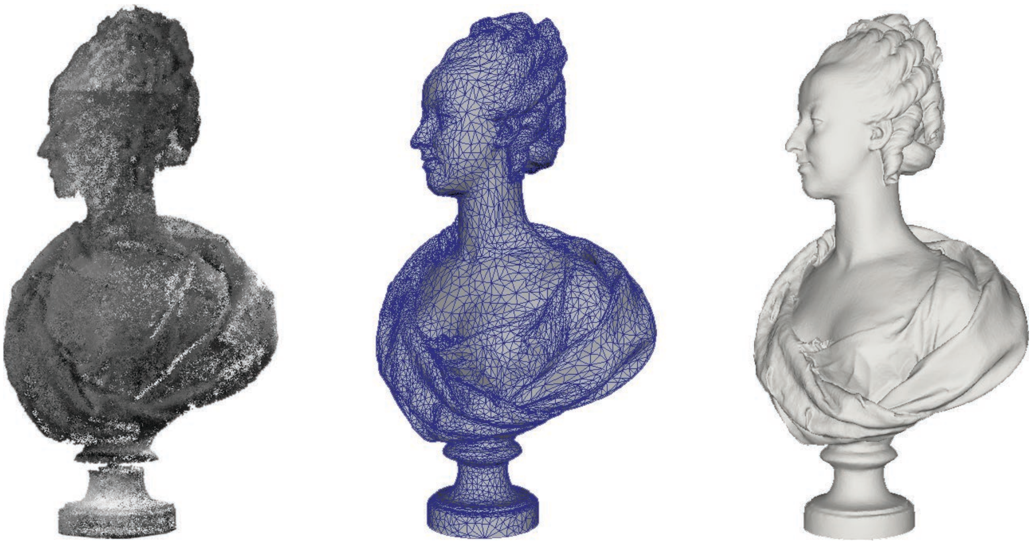

Fig. 3 Steps of laser-based modelling: point cloud, geometry, ambient occlusion render.

- **Image-based modelling:** The 3D reconstruction by image-based modelling is perfectly applicable to most objects with a more 'simple' geometric structure. This modelling system is used to extract the 3D geometry of the object based on the determination of matching points between the different pictures of this object. The links established between photos during the calibration phase allow extracting textures from one or more images, which are then projected onto the model to reproduce the visual appearance of the object. Using image-based modelling provides 3D models with a geometric structure adapted to multimedia broadcasting but responding also to the requirements of visual rendering and extraction of dimensional information (fig. 4).

Fig. 4 3D reconstruction by image-based modelling.

- **Hybrid (laser/image) modelling:** Some kinds of objects, because of their complex geometrical structure, require a combination of treatments. In this case it is necessary to separate the different parts of the object based on their structure and their materials so they can be treated independently. The structure of the object is processed by image-based modelling or interactive modelling starting from relevant profiles and 3D coordinates, while the laser-based modelling is used for the sculpted part, on which is applied a material in order to reproduce its visual appearance (fig. 5).

Fig. 5 Example of hybrid reconstruction using interactive modelling and laser-based modelling.

As a result, this project presented an opportunity to assess the relevance of the most appropriate reconstruction methods according to the heterogeneity of the treated objects (fig. 6).

Fig. 6 3D reconstruction methods: **a.** Laser-based modelling, **b.** Image-based modelling, **c.** Interactive modelling, **d.** Hybrid modelling, **e.** HD photography.

Interactive Visualization

3D Database

All acquired information and data developed during the surveying campaign and the geometric reconstruction are structured and stored in a 3D database developed under the project NUBES (http://www.map.archi.fr/nubes). The database, developed in MySQL, retains four types of information: documentary, raw surveying, data processing, and optimized files for 3D visualization in real time. An interactive 3D scene, developed in Virtools DEV, allows the visualization and the handling of 3D representations.

- *Documentary and historical information* inserted by cultural institutions (mainly curators of the Public Establishment of Versailles); the data associated with each element are in connection with the management software of the collections of the Palace of Versailles TMS (The Museum System).
- *Raw surveying data* collects all the files included in the surveying process: 3D laser files (Point clouds), High Definition pictures, and so on.
- *Data processing files* concerning modelling software files (Maya, ImageModeler, Nubes, Rapidform) and textures files for restitution of the visual appearance (JPEG, PNG, and so on).
- *Optimized files for 3D visualization* used in particular in the part of the database allowing the handling of representations in real time.

Virtual composing of 3D scenes

The 3D restitution of the rooms is based on an approach of virtual furnishing guided by the assumptions made by the curator. A photographic environment (fisheye) representing the external environment is first added to the representation of the geometry of the rooms, then digitized pieces of furniture are integrated, and finally a lighting transport calculation is performed to merge the 3D renders of the rooms and furniture based on a common illumination condition (fig. 7).

Fig. 7 Virtual composing of 3D scenes (render of the room, addition of the external environment, integration of furniture, lighting transport calculation).

Fig. 8 Interactive scenes: example of 3D restitutions of rooms.

The interactive scenes are the result of the use of panoramic images with cubic projection oriented in a 3D scene containing the envelopes of objects (fig. 8). As all elements of the scenes keep a constant link with the 3D database, it is possible to display and manipulate, in this space, a selected element in the scene, to access all its information (technical, documentary, and so on), and also to search and collect items based on spatial, temporal and/or semantic criteria (fig. 9).

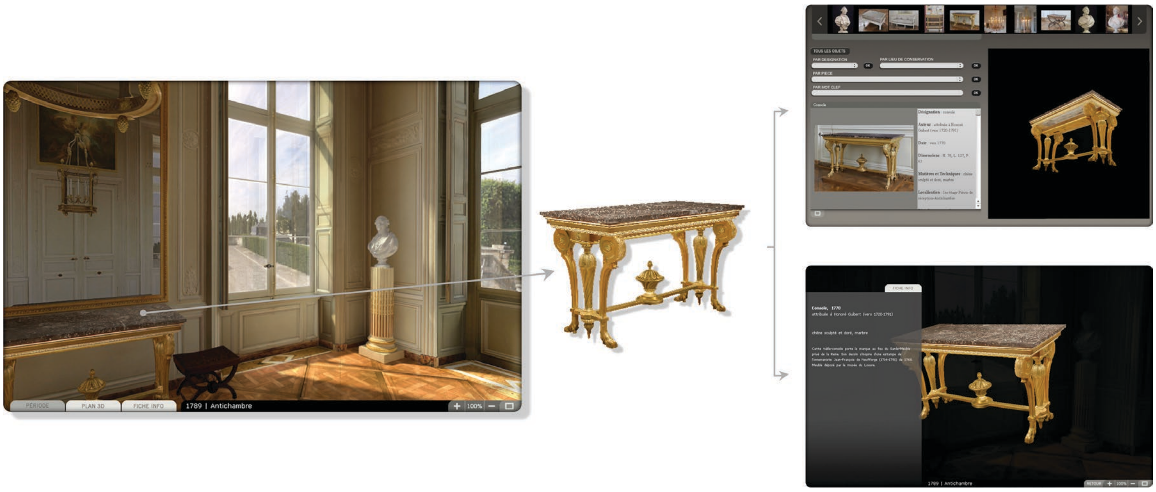

Fig. 9 Link between furniture of interactive scenes and 3D database.

Interactive Uses

The development of this system of interactive visualization has been chosen according to two main purposes, defined with MCC and the Public Establishment of Versailles. This 3D representation of the rooms, coupled with the database, allows for two types of use:

- *Online and on-site use, as a complement to the visit.* The interactive visualization of rooms online or on-site, through interactive terminals installed on the ground floor, allows the public to virtually visit the rooms of the first floor. Visitors can also use it as a complementary cultural offer, giving access to more realistic restitutions of the furnishings and to documentary and historical information, and allowing them to handle the furniture and so to discover hidden aspects.
- *Online use of an internal version of the database for storage and conservation of 3D data, pictures and documentary information.* Researchers, historians and curators involved in the project can use the database to consult the data already online, or to add/modify for each piece of furniture elements such as its documentary and historical information, photographs, name, place of conservation, or inventory number.

Future Steps

The next step concerns the modelling of the Queen's room and its evolution in Marie Antoinette's time at the end of the eighteenth century, and in the nineteenth century, when it was necessary to refurnish the palace that had been emptied by the Revolution. Marie Antoinette did make changes to the furnishings of this room by ordering the furniture '*aux épis,'* which has now been returned. In order to complete it, elements conserved in foreign museums will be modelled, in particular a chair preserved at the Getty Museum in Los Angeles. But the preceding furnishing must also be mentioned. Pieces of furniture which have not been found, such as seats, will be highlighted by a specific graphic processing. Fortunately, some pieces of furniture are known, such as the mechanical table preserved at Waddesdon Manor, which has already been modelled in the database. The user will be able to visit two successive states ordered by Marie Antoinette, which will show the evolution of her taste and fashion.

After the sale of the furniture during the Revolution, the bedroom, like the rest of the Petit Trianon, was completely refurnished for the Empress Marie Louise in 1810–11. This furniture has been preserved and will also be modelled. But unlike the previous state, which focused mainly on digitizing furniture, the restitution of these furnishings needs to take into account many textile elements, in particular the hangings and drapes that were especially created for the room and which covered its ceiling and walls, giving the room a tent-like appearance. It will be a challenge to define and implement the surveying techniques and data processing methods that are most appropriate for reconstructing this particular aspect.

Finally, the latest changes to the furniture were brought about by the Duchess of Orleans in the 1830s. The white satin drapes of Marie Louise were replaced by blue ones, and the aspect of the room was radically transformed. One of the challenges in modelling this phase will be to reconstruct this change of textile on seats that were conserved from one reign to the next.

Conclusion

In addition to detailed reconstructions of the Petit Trianon's rooms and furnishings, this ongoing project also takes into account a temporal and historical dimension. In fact, visitors can discover a new interaction with places and objects which until now could only be partially accessed and known about. Based on the application of tools and techniques that are used and developed in the laboratory, this project is part of the process of conservation and scientific investigation of the site, but responds also to recovery concerns and constitutes an innovative communication tool.

More information about the project is available on its website:
http://www.map.archi.fr/3D-monuments/site_trianon

Bibliography

Debevec, Paul, Taylor, Camillo, Malik, Jitendra, 'Modeling and Rendering Architecture from Photographs: A hybrid geometry and image-based approach', in *SIGGRAPH* (1996), pp. 11-20.

De Luca, Livio, Busayara, Chawee, Stefani, Chiara, Véron, Philippe, Florenzano, Michel, 'A semantic-based platform for the digital analysis of architectural heritage', in *Computers & Graphics*, 35 (2011) 2, pp. 227-241.

De Luca, Livio, Véron, Philippe, Florenzano, Michel, 'Reverse engineering of architectural buildings based on a hybrid modeling approach', in *Computers & Graphics*, 30 (2006) 2, pp. 160-176.

Levoy, Marc, 'The Digital Michelangelo project', in *The 2th International Conference on 3D Digital Imaging and Modeling* (1999).

Illustrations

Fig. 1-9 All illustrations by the authors.

The Vaults of Villa Reale in Monza

A 3D Virtual Model for the Accurate Understanding of their Genesis and Construction Techniques

Daniela Oreni (Politecnico di Milano, Italy)

Raffaella Brumana (Politecnico di Milano, Italy)

Branka Cuca (Politecnico di Milano, Italy)

The survey campaigns of the interiors of the Villa Reale in Monza, which have been conducted from 2002 to 2012, have enabled the creation of a virtual three-dimensional model of the building using both photogrammetric and laser scanner techniques. During the measurements the geometry of the principal rooms, all covered by brick or wooden vaults, was accurately investigated. Analysis and cross-checking of dimensional constructive data with information obtained from direct inspection of the extrados of the vaults led to important observations about the genesis and construction method of the vaults. Moreover, when compared with architect Giuseppe Piermarini's original drawings and with contemporary construction manuals, this information sheds light also on the shape of the wooden centrings that were used for the construction and the arrangement of the bricks.

The geometrical and structural 3D model built for the Villa has both a scientific and a practical value. On the one hand, it can provide support for future conservation programmes; on the other, it can be used to disseminate specific thematic knowledge to the public via an online platform.

Villa Reale in Monza: Historical Notes

Maria Theresa of Austria (1717–1780) decided to build the Villa in Monza for her son, Archduke Ferdinand of Austria-Este, when he was appointed Governor General of Austrian Lombardy. The Villa was planned in 1777 by the imperial architect Giuseppe Piermarini and built in only three years, on a crossroad between Milan and Vienna, the imperial capital.

Less than a century later, during the French government in Lombardy, the Viceroy of the new Italian Kingdom established his main residence in the Villa and the building took the name of Villa Reale (Royal Villa). The Austrians returned to the Villa only after the fall of Napoleon and they remained there until the Second War of Independence, in 1859, when the Villa was definitively left to the House of Savoy. Due to the murder of the King of Italy Umberto I in the Villa on 29 July 1900, while he was attending a sporting event, the building was closed and the King's son, the new King Victor Emmanuel III of Savoy, moved most of the furniture to other royal residences in Italy. In 1934 the whole complex of the Villa Reale, with the exception of the south wing, was given as a present to the municipalities of Milan and Monza. After the Second World War the buildings were first occupied by military troops and then largely abandoned, leading to severe degradation of the monument. After a long period of neglect, also due to the fragmentation of the current government's properties, a process of restoration of the Villa has only recently started.

Despite these unfortunate historical events and the successive changes of ownership, the Villa Reale has maintained until today the original plan drawn by Piermarini. The transformation of the building in the nineteenth century concerned only limited portions of the structures, leaving intact the spaces and volumes of the *piano nobile* and the main rooms of the central part. Later modifications focused on the furnishings and rich decorations, in order to comply with the changing needs of the court. New ways of court life led to different uses of the spaces and to new functions for each room, but without modifying the original structures.

Instruments and Survey Methods for 2D Representation and 3D Modelling of the Complex

Interior and exterior survey campaigns of the Villa Reale have been conducted between 2002 and 2012. The initial purpose of the surveys was to supply preliminary information on the complex in view of the restoration and reuse of the central building, which was awarded in an international competition in 2004.

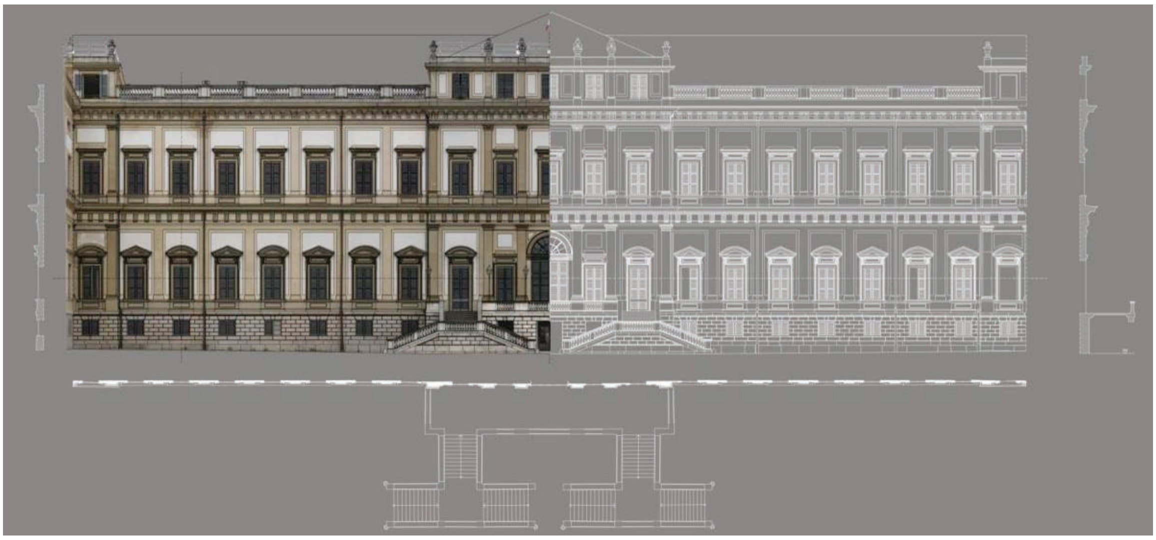

Fig. 1 Drawing of the main front of the Villa Reale, with rectified image, vertical and horizontal section of the building.

During the phase of survey planning, it was decided to use different scales for measurement and representation, according to the various requirements of analysis of the structures and surfaces. This led to the integration of different instruments, technologies and methods: manual survey, topographic, photogrammetric, laser scanner and GPS survey (fig. 1). In particular, 355 rooms were surveyed in detail, geometrically representing the inner surfaces, fine decorations and wooden elements, using 2D 'box system' representations and texturing them with rectified images (fig. 11). Based on this survey virtual 3D detail models were made for 71 rooms (until March 2012), using both photogrammetric and laser scanner survey products, integrating orthophotos and 3D CAD models.

The limited use of handy scan and reverse engineering (fig. 2) was adopted to reproduce particular decorative elements with the aim of documenting their state of conservation and enabling the work of restoration professionals at a great level of detail (scale 1:1, 2:1).

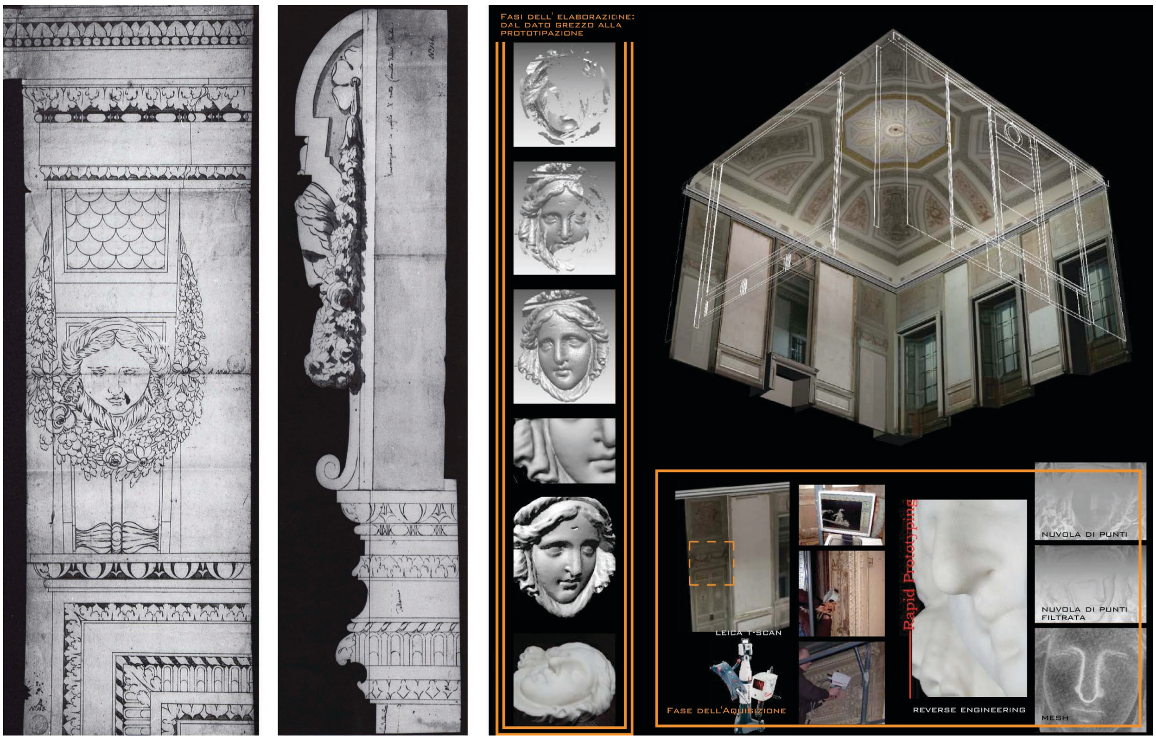

Fig. 2 On the left two drawings by Piermarini (c. 1780), useful to build the decoration template of the interior doors. On the right, the process of reverse engineering to reproduce the same decorative element.

All the survey data were geo-referenced in a unique geographic reference system and were published in the web-portal of the *Virtual Museum of Villa Reale,* where it is also possible to navigate the 3D virtual models of all the rooms. The web-portal is at the moment a prototype and the property of the Region of Lombardy, the authority supervising the project. It is expected that the web-portal will become public in the near future, offering the functions of view, discovery and download to professionals and the wider public.

Finally, for didactic purposes, and in keeping with the use of virtual models to tell stories about the past (adopted also by other famous monuments such as Schönbrunn and the Louvre), a few short movies illustrating the life in the Villa over the centuries were made and published at the portal (fig. 3).

Fig. 3 Still of a short movie illustrating the past life in the main room of the Villa Reale: the Ballroom. The 3D model of the room was created using topographic, photogrammetric and laser scanner data.

Survey and Virtual Models for the Analysis and Comprehension of Structural Elements and Techniques: the Vaults of the Central Part of the Villa

The aim of this part of the work was to identify a methodology of survey, documentation and 3D representation for complex vaulted structures, using both advanced instruments and survey technologies, and to compare these data with the original drawings and the technological information provided by construction manuals from the time of the building's creation.

The dimensional and geometrical data on the shape of the cloister vaults were analysed from a constructive and structural point of view, comparing information obtained from the survey with direct observation of the extrados of the vaults. At the same time, an attempt was made to cross this technological information with information derived from the analysis of the original section drawings by Piermarini, which were used as a guide to build up the cover structures of the rooms (fig. 4). In order to reconstruct the building process we used instructions from manuals supposedly known by the architect. In particular, we tried to understand how the ancient builders drew and built the wooden centrings to obtain the exact shape of the vaults planned by Piermarini, starting from the shape of the room in plane and from the height of the vault (figs. 5, 6, 7).

This method of investigation of the old structures and their constructive techniques represents a reverse knowledge process, starting from observing what exists to virtually reconstructing hypothetical building phases, considering not only the geometry and the thickness of the walls, but also the materials and the actual disposition of the constructive elements (fig. 8). In this way it was possible to examine the constructive genesis of the vaults and to identify anomalies in their shape with respect to the ideal one, which is useful also for subsequent diagnostic analysis. The final result of this inverse process was the creation of a 3D virtual model of the cloister vaults, mapped with orthophotos obtained as one of the products of the photogrammetric survey (fig. 10).

The following examples illustrate this kind of geometrical and structural research on the cloister vaults of the Sala degli Uccelli ('Birds room') and the Sala da Bigliardo ('Billiard room') on the *piano nobile* of the central block of the Villa.

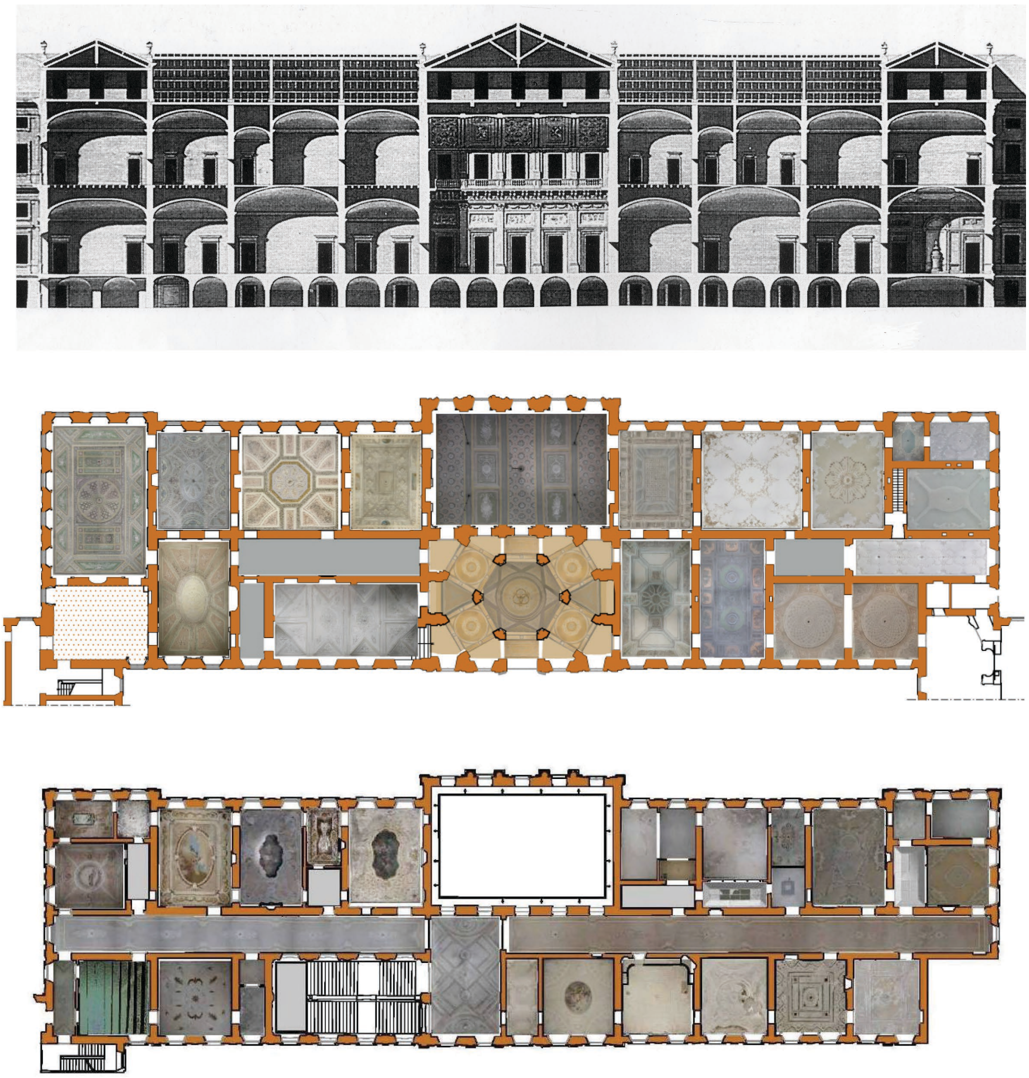

Fig. 4 Above, original longitudinal section (south-north) and the central part of the building, drawn by architect Giuseppe Piermarini in 1780. Centre and below, the surveyed plans of the building (first and second floor) with the orthophotos of the vaults of the rooms.

Example of Analysis of Traditional Method of Cloister Vault Construction

The reconstruction of the precise geometry of the cloister vault started from the drawings with longitudinal and transversal sections of the square room, obtained from the laser scanner point cloud. The aim was to identify the arches of the two barrel vaults, which is useful at the end of the process to compare the *real* shape with the *ideal* shape.

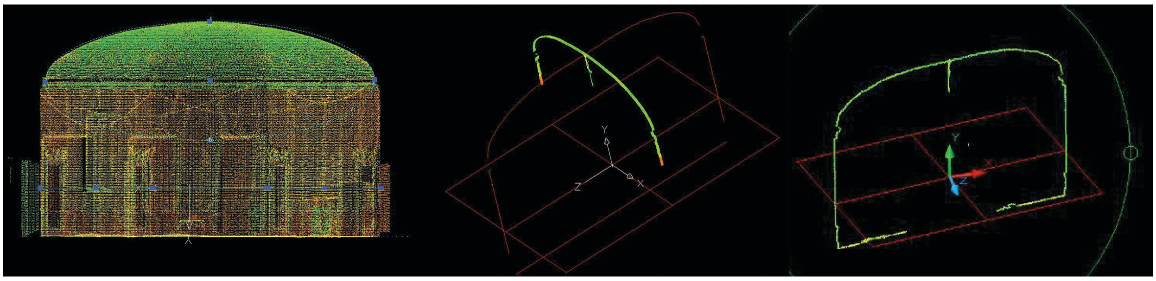

Fig. 5 Process of extraction from the laser scanner point clouds of the transversal and longitudinal sections of the room.

The second step of our process consisted in the reconstruction of the ideal geometry of the sections of the cloister vault, starting from the surveyed plan of the Sala degli Uccelli, using the projective method explained in the manual written in 1737 by the Italian architect Guarino Guarini. Assuming that a cloister vault is geometrically the result of the intersection of two orthogonal barrel vaults, to build the vault it was first necessary to know the two generative curved lines of the two barrel vaults. So the method explained by Guarini consisted in the drawing of the second curved line, for example the longitudinal one, starting from the rectangular shape of the plan of the room and from the curved line of the vertical section. This transversal curved line could be drawn knowing the dimension of the room and the height of the vault, as represented in the CAD sequence below (in blue). Using the diagonal of the rectangular plane it is possible to transfer the height of the transversal section (in red) onto the long side of the rectangular, in order to draw the curve line of the longitudinal section.

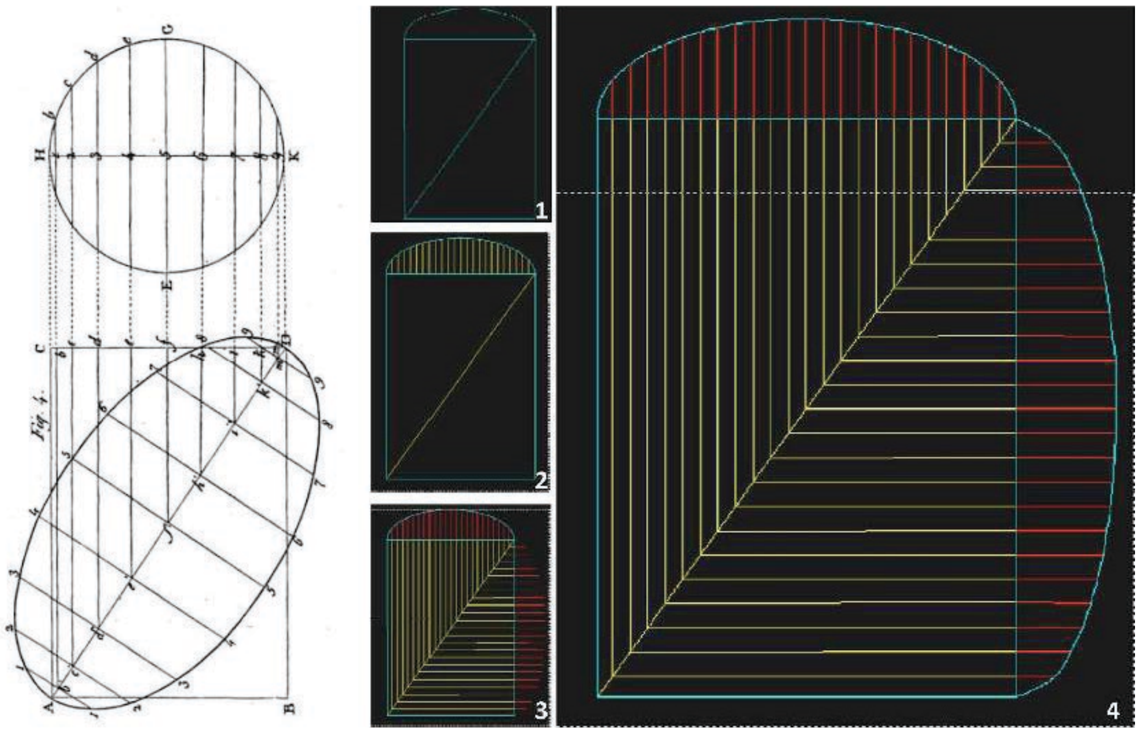

Fig. 6 On the left, construction of the curved lines of the vault by the projection method of Guarino Guarini. On the right, the process of drawing of the two curve lines of the two barrel vaults.

At this point it was possible to make a comparison between the ideal section of the cloister vault, reconstructed with the projective method (blue line) and the actual shape derived from laser scanner survey (red line). This step was useful to identify structural anomalies, such as crushing and implosion areas. This information, which must be constantly monitored and updated, could be essential to identify areas in which to perform additional diagnostic tests.

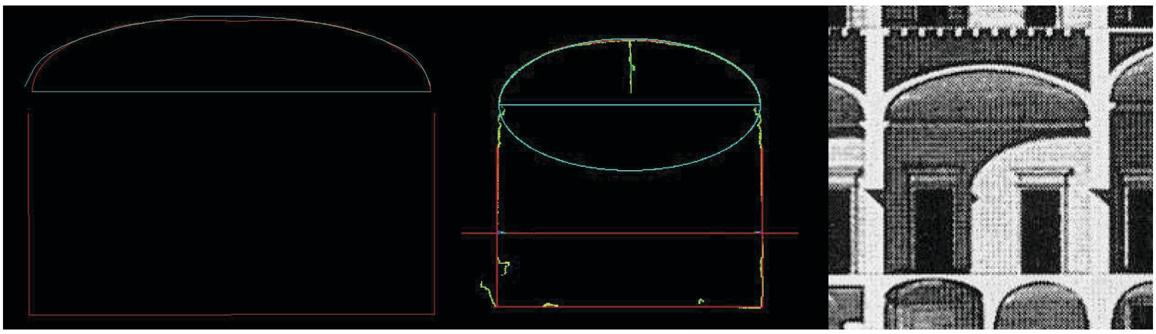

Fig. 7 Left and middle, comparison between the ideal (blue) and real (red) shape of the vault. On the right, detail of Piermarini's longitudinal section (Sala degli Uccelli).

Once the geometrical genesis of the vault was detailed, its actual construction was investigated, analysing the extrados to identify the texture and the arrangement of the bricks. When possible, thicknesses, materials, textures of masonry, and metal or wooden tie-beams were always accurately observed. This provided useful points of comparison also for those areas in which information was not directly obtainable. In this case the nineteenth-century construction manual of Gustav Adolf Breymann was used, with a focus on the different pattern arrangements in the volume on stone building and wall structures. Like many other ancient manuals, Breymann explains the disposition of the bricks in the cloister vaults (fig. 8, centre) and the shape of the wooden elements of the centrings (fig. 9, above right).

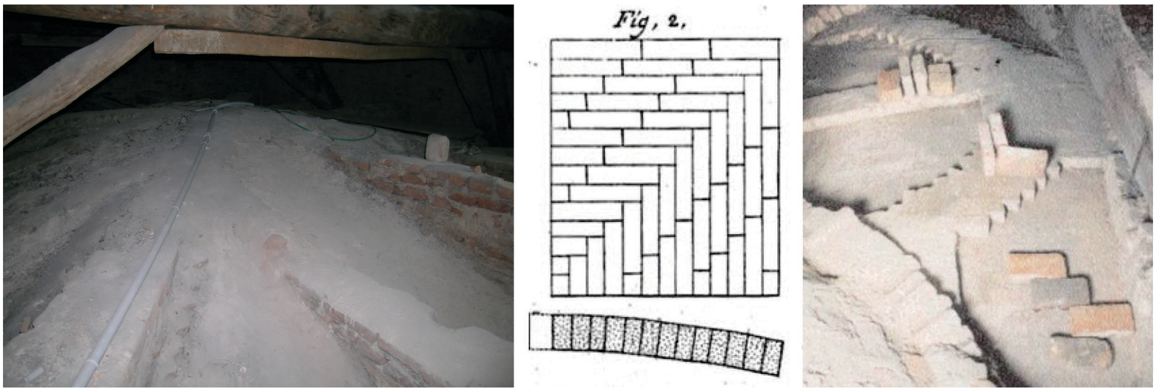

Fig. 8 On the left, image of the extrados of the vault of the Sala dei Quadri ('Paintings room'). Middle and right, example of herringbone pattern of bricks in the cloister vault.

Starting from Breymann's drawings and text, we simulated in 3D the different elements that plausibly composed the wooden centrings used to build the cloister vault of the Sala da Bigliardo ('Billiard room'), in a process of 3D virtual reconstruction. In particular Breymann gave instructions on the disposition of the wooden vertical elements, in function of the dimensions of the room and the quality of the wood (fig. 9). After the virtual construction of the centrings, a wooden frame following the exact shape of the underside of the vault was built. The boards were laid on the frame until the vault was complete and self-supporting (fig. 10).

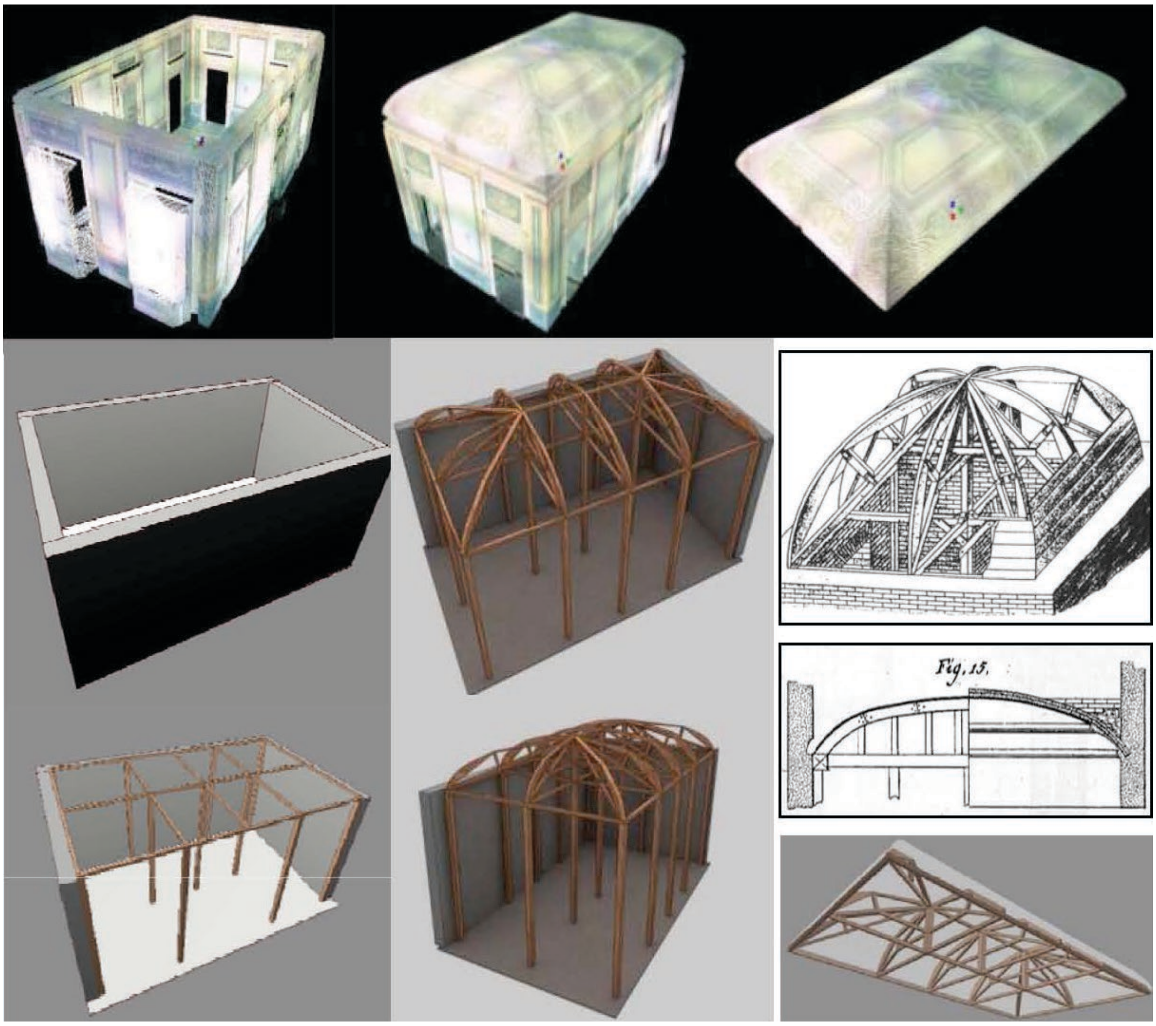

Fig. 9 Simulation of the building process of the vault, starting with the disposition of the wooden centrings. The drawings on the right were extracted from Giovanni Carbonara, *Trattato di restauro architettonico*. The precise shape of the room is derived from laser scanner survey.

The last step in the simulation of the construction of the vault consisted of the 3D virtual reconstruction of the masonry, starting from the arrangement of the bricks oriented along diagonal axes (fig. 10). For the room in which it was not possible to analyse directly the extrados, the virtual reconstruction of the thickness of the vault was drawn in analogy with the surveyed vaults. This was possible because the building was built in a single construction phase, following a unitary plan.

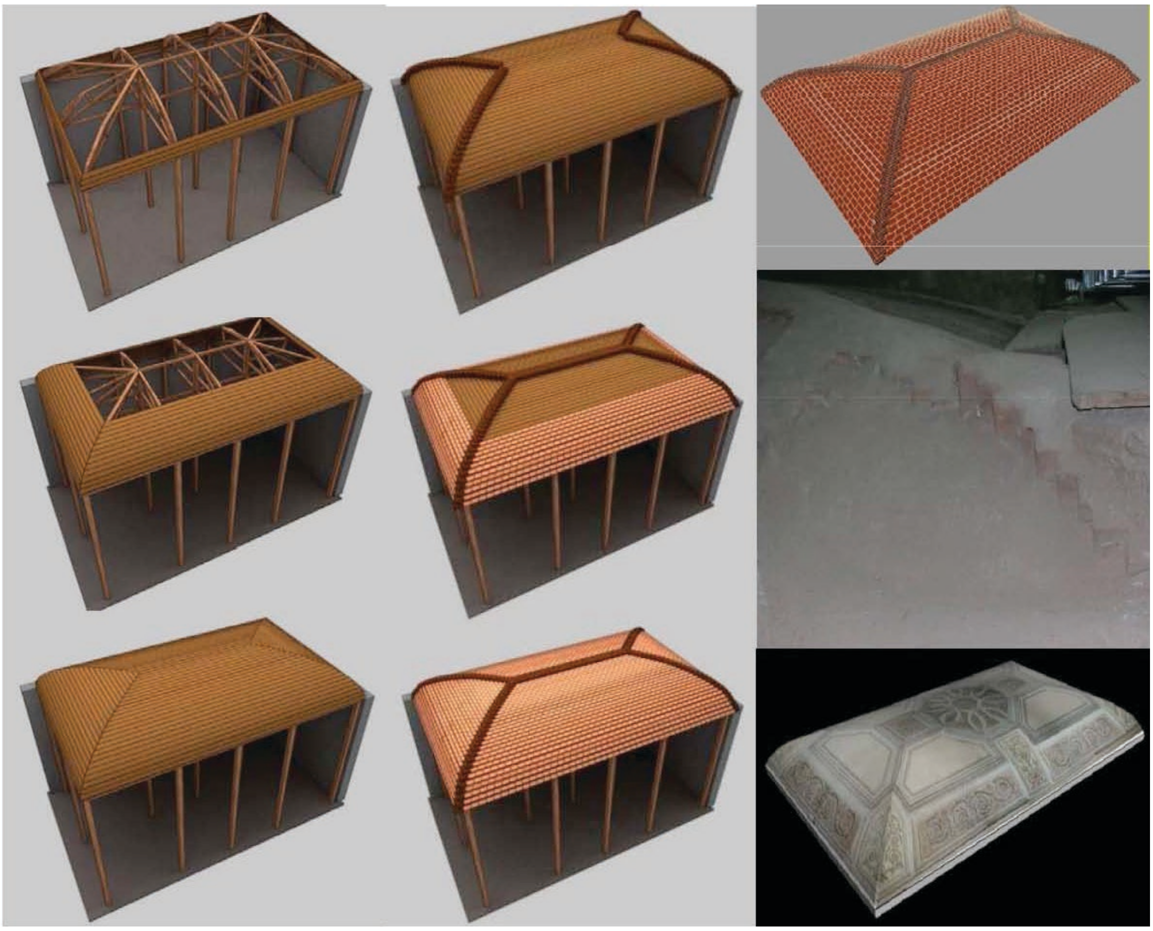

Fig. 10 Simulation of the construction of the cloister vault of the Sala da Bigliardo, with the arrangement of the bricks, as observed in the extrados of the vault. At last the 3D model of the vault was textured with orthophotos.

3D Virtual Model for Preventive Conservation and for Simulation of Reuse

The 3D detailed virtual models of the Villa, useful for improving remote access of 3D data, can in the future provide support for advanced programmes of preventive conservation, in order to guarantee sustainable interventions and maintenance over time. In particular, the 'box-system' (fig. 11) – which is similar to the traditional mode of architectural representation combining plan, section and elevation – makes it possible to represent technological elements not as single but as interconnected units. The open source software and tools that were used to create the infrastructure, which can host both geometrical and historical survey data and models, can be useful for analyses of materials and their degradation across the whole complex.

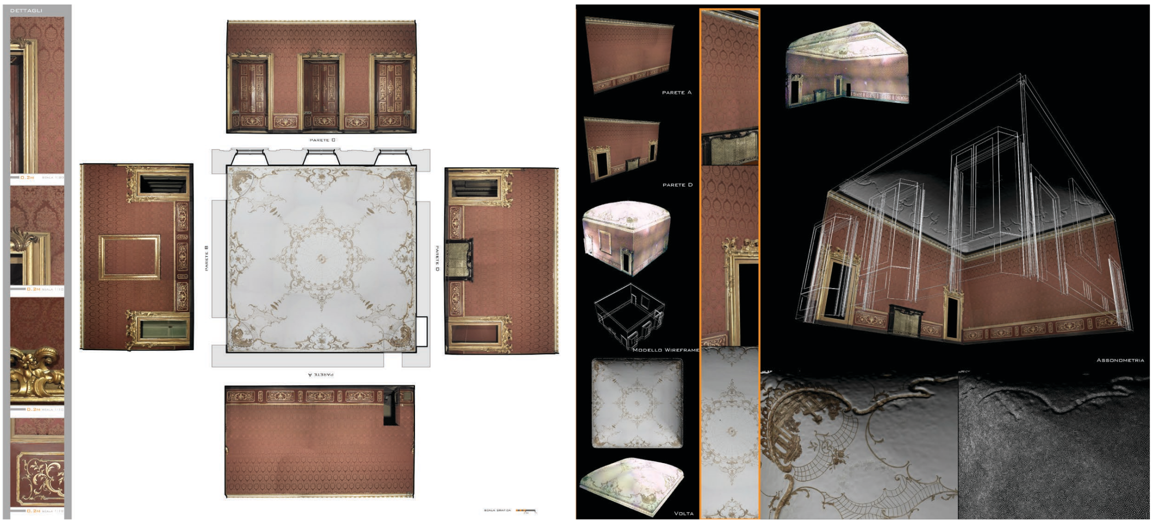

Fig. 11 Left: 'Box system' representation of the Salotto: plan, sections and fronts of the four walls. Right: Three-dimensional model of the room, textured with rectified images. The high resolution of the model enables the user to navigate the rectified images up to a scale of 1:20.

Thus, 3D models of ancient vaults of high geometric precision and incorporating also the exact thickness of the walls, the materials and the disposition of the elements, may support complex analyses on the state of preservation of the buildings and the stability of their structures. In fact, the proposed method shows that through an accurate 3D survey of the structures it is possible also to get all the basic geometric data needed to derive information on the structural genesis of the elements and on the construction methods used in the past. These basic data are useful also to evaluate the structural behaviour of the vaults and to identify geometrical anomalies in the structures.

At the same time, the complex survey and models of the structures and the decorative elements can facilitate the planning of restoration of different parts of the building. The extrados of the vaults and the rooms were surveyed and modelled in a single system. Thus the walls, floors, vaults and their connections can be analysed as one structural whole and each single room can be treated as a sub-unit in a larger system. This can be particularly useful when the structures are fragile and need to be monitored, for example the wooden hanging vaults in the central part of the building (fig. 12).

Fig. 12 Above, images of the extrados of the wooden vault of the Ballroom. Below, 3D model of the vault.

Finally, the high-resolution rectified images, textured on 3D models, make it possible to plan and simulate future uses of the rooms, including the disposition of the furnishings (fig. 13). This is a useful tool for conservation professionals but also for the public administration, as it enables them to make informed decisions about the preventive maintenance of the monument.

Fig. 13 Simulation of future use of the rooms, using the detailed 3D model of the rooms.

Bibliography

Achille, Cristiana, Brumana, Raffaella and Fassi, Francesco, 'Application of multiple techniques for the survey, 3D modeling and virtual representation of the internal rooms of the Real Villa in Monza', in *Optical 3-D Measurement Techniques VIII*, eds. Arnim Grün and Heribert Kahmen (Zurich, 2007), pp. 312-320.

Becchi, Antonio and Foce, Federico, *Degli archi e delle volte: arte del costruire tra meccanica e stereotomia* (Venice, 2002).

Breymann, Gustav Adolf, *Allgemeine Bau-Constructions-Lehre, mit besonderer Beziehung auf das Hochbauwesen* (Stuttgart, 1849-1854); Italian translation: Vallardi, Francesco, *Trattato generale di costruzioni civili* (Milan, 1884), Vol. I 'Costruzioni in pietra e strutture murali'.

Brumana, Raffaella, Fassi, Francesco, Cuca, Branka and Oreni, Daniela, 'Remote virtual access to 3D Photogrammetry: e-vmv virtual museum of the Villa Reale in Monza', in *VSMM Int. Society on Virtual Systems and Multimedia* (Cyprus, 2008).

Carbonara, Giovanni, *Trattato di restauro architettonico* (Turin, 1996), vol. II.

Cuca, Branca, Oreni, Daniela and Brumana, Raffaella, 'Open Source meets preventive conservation: web based tools for preventive conservation of architectural heritage', in *PreCoach2011. Proceedings of the International Conference on Preventive Conservation of Architectural Heritage* (Nanjing, China, 2011), pp. 55-67.

De Giacomi, Francesco, *La Villa Reale di Monza* (Milan, 1984).

Fassi, Francesco, Achille, Cristiana, Brumana, Raffaella and Tuncer, Hande, 'Application of mixed technique for the 3D modelling of the Noble floor of the Real Villa in Monza', in *ISPRS*. *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, 36 (2007) 5/C53, pp. 758-763.

Giuseppe Piermarini. I disegni di Foligno. Il volto piermariniano della Scala (Milan, 1998).

Guarini, Guarino*, L'Architettura civile* (Turin, 1737).

Kraus, Karl, *Photogrammetry – Geometry from Images and Laser Scans* (Berlin, 2008).

Remondino, Fabio and Menna, Fabio, 'Image-based surface measurement for close-range heritage documentation', in *IAPRSSIS*, 37 (2008) 5/W1, pp. 199-206.

Rosa, Marina, *Villa Reale di Monza* (Viterbo, 2003).

Illustrations

Fig. 1, 3, 5, 10, 11, 13 Drawings by authors.

Fig. 2 On the left *Giuseppe Piermarini* (Milan, 1998). On the right, drawings and photos by authors.

Fig. 4 Above, De Giacomi, *La Villa Reale di Monza* (Milan, 1984). Centre and below, drawings by authors.

Fig. 6 On the left, Guarini, *L'Architettura civile* (Turin, 1737). On the right, drawings by authors.

Fig. 7 Left and middle, drawings by authors. On the right, De Giacomi, *La Villa Reale di Monza* (Milan, 1984).

Fig. 8 On the right, photograph by authors. Right, Breymann, *Allgemeine Bau-Constructions-Lehre* (Stuttgart, 1849-1854); Italian translation Vallardi, *Trattato generale di costruzioni civili* (Milan, 1884), vol. I.

Fig. 9 Drawings by authors. On the right, Carbonara, *Trattato di restauro architettonico* (Turin, 1996), vol. II.

Fig. 12 Photographs and drawings by authors.

Romanian Court Residences

The Potlogi Palace: History and Virtual Recording as Restoration Tools

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Romanian Countryside Residences

The court residences in Walachia – the historical province situated in the Southern part of Romania – constitute an important chapter of Romanian architectural history and heritage. Studies of their development in the seventeenth and eighteenth centuries have regarded their architecture as a response to political and economic conditions and to their owners' social need for representation.

Walachia was established as an independent state at the beginning of the fourteenth century. Until the end of the sixteenth century, the ruling princes' residences – preserved as ruins and archaeological sites – are the only proofs of the existence of secular masonry architecture. There are no traces of such residences belonging to the 'boyars' (Romanian noblemen) in the same period. This changed in the early seventeenth century. New economic opportunities encouraged the boyars to reconsider their countryside properties. They decided to spend the major part of their time there so as to have a better control of their lands. This initiated a very consistent building activity all over the country. Since these residences had an important defensive role the pattern is more or less the same everywhere: all of the approximately sixty court residences built in the seventeenth century are fortified.

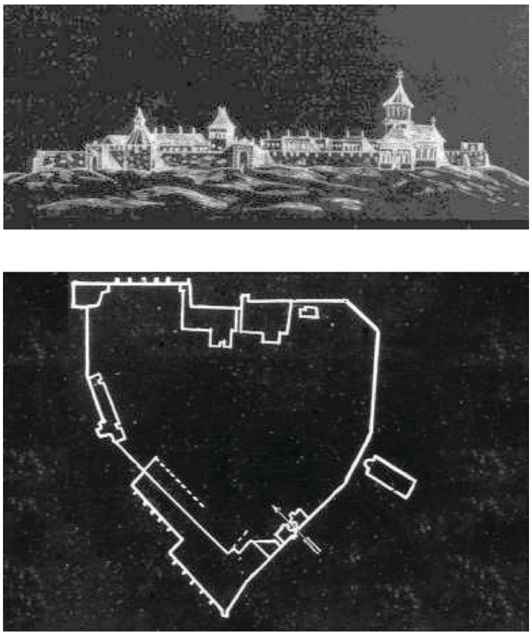


Fig. 1 The court at Brâncoveni, built ca 1634.

Placed on a hillside or on an elevated stretch of land, the large court precinct is enclosed by a wall. The buildings (the house of the landowner, the kitchen, the servants' building, and other annexes) are placed against this wall and oriented towards the central space, which is left empty in order to shelter the peasants and their goods in the case of an attack. A well is always present in the same space. Sometimes a tunnel offers a possibility to escape in the case of a siege. The chapel of the court is located outside the wall and has its own fortified precinct.

Fig. 2 The ruler prince Constantin Brâncoveanu.

The ruler prince Constantin Brâncoveanu (1688–1714) was the creator of a new pattern for such residences. The palaces he ordered were built to shelter himself, his family and his retinue, corresponding to an itinerary, repeated every year, that connected his Bucharest palace with his summer residence in the city of Târgoviste (the old Walachian capital). Their architecture reflects the prince's requirements regarding the ceremonial and etiquette to be observed by him and his court members. The Potlogi palace, erected in 1698, was the first to present the characteristics of this new orientation; its architectural features constituted the prototype for the court residences built later by the prince.

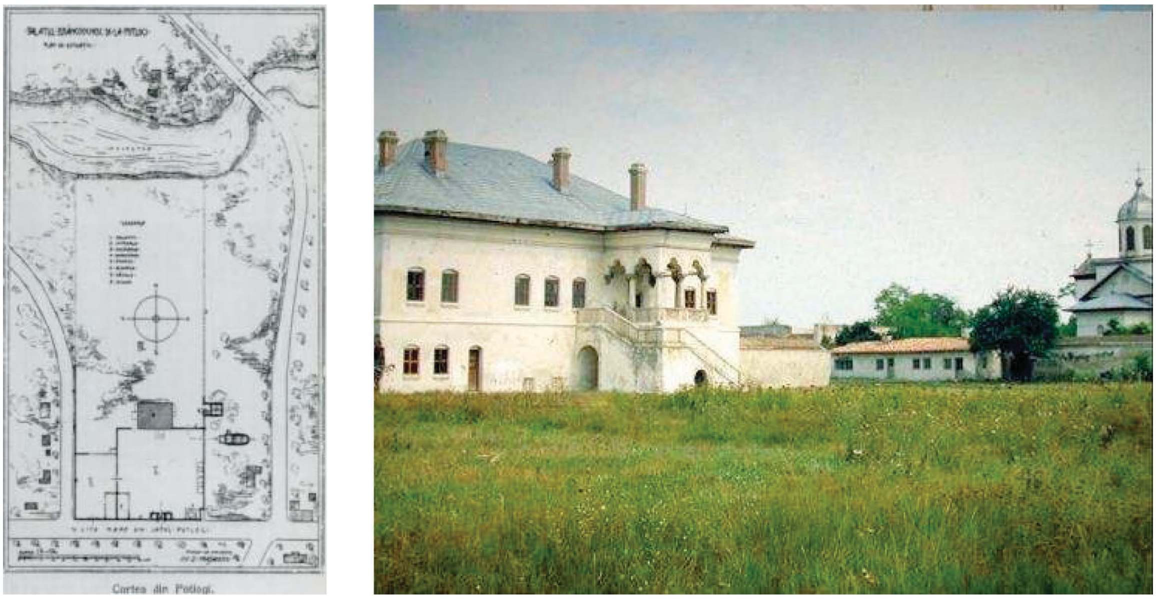


Fig. 3 The Potlogi Palace.

The architectural characteristics of the palace are influenced by contemporary North Italian residences. This hypothesis was put forward eighty years ago by Nicolae Ghica Budesti,[1] based on the known presence of numerous Italians at Brâncoveanu's court, and has been confirmed after studying Italian archives and the literature on residences in the Veneto. Just like its models, the Romanian residence at Potlogi is placed on a flat terrain adjoining a river. A rectangular wall surrounds the court components on three sides, the fourth side being taken up by the river. The house/palace has a central position: the front side faces the entrance yard, which contains also the court annexes; the opposite side has a loggia oriented towards the garden and the water. The court chapel is placed outside the wall in its own precinct. The organization of the spaces inside the palace – from the symmetrical plan and the superimposed loggias to the vaulting system and the carved stone decoration – is inspired by the same models.[2]

Nevertheless, the palace's architecture also bears the marks of an oriental influence, probably from Constantinople. The stucco decoration, both of the interior and the exterior of the building, is clearly inspired by contemporary Ottoman architecture.[3] By contrast, the entrance apparatus (composed by the stairs and the belvedere) and the volume of the palace follow the model of earlier Walachian architecture. It has indeed been demonstrated that the architecture of the Potlogi palace constitutes an original local synthesis, made according to the prince's will.

Fig. 4 Potlogi Palace: images illustrating the assimilation of different influences.

From this point of view, the Potlogi palace instituted a new pattern that changed the face of residential architecture in Walachia. Thereafter the other court residences of the prince used the same compositional principles and decorative elements, and in the next fifty years the Romanian boyars, too, adopted the same architectural characteristics, at a smaller scale, for their own residences.

Virtual Modelling of Historical Architecture: Notes on the (Potential) Reversibility of Restoration

The relationship between virtual modelling and restoration begs an important question: is the reconstruction of a virtual space equivalent to the implementation of a restoration project, or does it belong to the sphere of representation? In other words: to what extent can an immaterial reality affect the critical approach of conservation?

The high sophistication of virtual modelling and simulation techniques prompts us to re-examine the relationship between reality and its representations, by thinking of 'virtual realities' as real worlds. As Bonollo has pointed out: 'Simulation opposes itself to representation, to the *re*-presentation of "that which has been", because it does not restitute a completed past, but refers to potential events, to eventualities, to "something that may be".'[4] 'Simulation' and 'virtuality' therefore constitute two contiguous instances. Simulation occurs when virtuality replicates a real geometry through a synthetic representation. Pure virtuality, by contrast, occurs when one chooses a 'hetero-representation', a more complex metaphor adapted to describing the sense of reality. Or, to quote Forte, 'Whereas simulation simplifies the contents of the real by schematising them (sometimes in a reductive sense), virtuality tends to extend and multiply them'.[5]

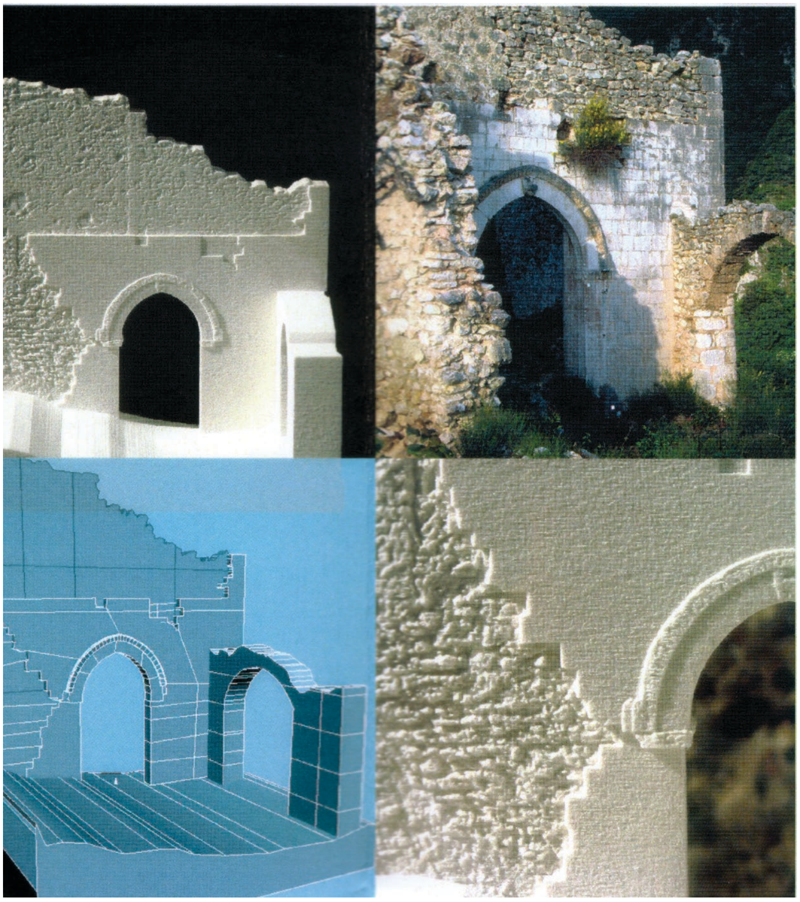


Fig. 5 Santa Maria church, Ancarano Castle (Perugia), 3D model of the façade.

Undoubtedly computer science (and especially its digital survey applications that are conceived for the representation of historical architecture) is the cultural sphere in which one can best discern this duality between tangible and intangible, between real and unreal. This duality amounts to a cognitive and critical exercise that expresses itself in three separate but complementary domains: aesthetics, in so far as the aesthetic values of the artwork are fully rendered by its digital representation; philology, in so far as this representation restitutes also the original meanings and values of the artwork; and conservation, in so far as the digital model represents not just the latest state of conservation but allows to trace back all previous interventions.

The latest virtual technologies make it possible to exploit the memetic abilities and the creative power of virtual reality in every field of human action. The digital processing of an image (if understood as a research method and not just a mere computer application) can significantly improve knowledge: a multiple screening of shots across all wavelengths, the subsequent comparison between the resulting images, and the use of digital techniques to separate texts, can for instance be used to read superimposed layers of text. Likewise, an accurate and critically conducted digital survey of a building can help to identify phases in its historical developments that are otherwise undocumented.

In the field of conservation, computers can be used as effective instruments to examine properties and behaviours of materials, and to monitor the design process in parallel with (or, preferably, in support of) the restoration itself, without affecting the material of the historical document itself. Digital surveys are therefore appreciated more and more as a special form of non-destructive investigation and as tools for a 'pre-diagnosis' of the health of a monument.[6] 'Virtual restoration' therefore seems an ideal instrument to integrate different cognitive means: it increases the legibility of data without acting on the material of the object, so that its impact is reversible at all times.

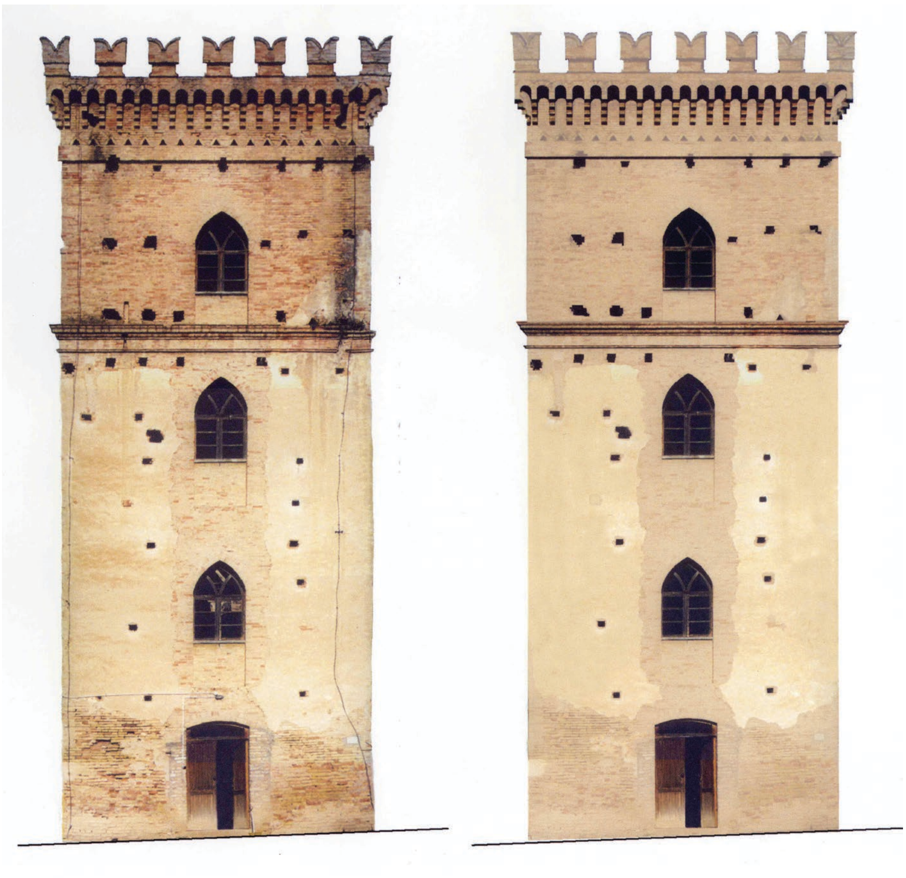


Fig. 6 Sterlich Tower, Spoltore (Pescara), example of virtual restoration.

The main, though not the only, goal of virtual restoration is to reproduce the appearance that the work would have after an eventual cleaning or restoration campaign. As noted by Forte: 'Virtual restoration, conducted not on the material object but on its representation, can yield data which, although present in the original object, are not directly discernible from its present condition. The added value of using virtual reality methods in the field of cultural heritage lies in the possibility of providing experiences, and therefore of initiating cognitive processes, even in the absence of physical (real) objects'.[7]

The use of digital modelling in the field of restoration can therefore serve a double purpose: putting emphasis on the information content of a model may result in a higher gnoseological value, while rendering the model as realistically as possible may also give it a documentary value. The purpose of digitized information, whether images or texts, is therefore not to make up for the inevitable deterioration of the original material, but to preserve at least its form, that is, its diachronically created image, untouched by time.[8]

Fig. 7 St. Augustin church, Cascia (Perugia), example of virtual anastylosis.

The particular prerogatives of the use of computers for the virtual restoration of a lost image or a lost building can be appreciated by looking at their specificities: working with a digital piece of information, one has the greatest freedom: it can be altered and copied countless times without any impact on the material object itself; which has substantial consequences on the principles of restoration: reversibility, compatibility, and minimal impact.

The method of virtual restoration allows simulating interventions while preventively reviewing the results. The process also enables one to try out interventions that are not possible in ordinary conservation practice. Virtual restoration must therefore be seen as parallel and complementary to traditional restoration, and a helpful tool for historical and philological research.

The Potlogi Palace: Digital Drawing and 3D Modelling

A complete study must necessarily start from a correct metric investigation in which the most suitable measurement techniques are integrated. The ultimate goal of these techniques is to analyse the structure and the damages caused by time or by incorrect restoration. By jointly using advanced laser scanning techniques and on-site surveys (conducted by historians and restoration experts), important results can be obtained that improve our understanding of the historical complexity and the construction characteristics of the monument. This information can be used for conservation projects.

The Potlogi Palace has been chosen for this case study for its particular historical and architectural value; it is particularly significant in that it represents an architectural reference model for similar buildings in the region. Because of its unique architectural features and its historical value, the building merited an in-depth survey, which for this reason was planned in two annual sessions, in conjunction with inter-university workshops in 2011 and 2012.

Fig. 8 Potlogi Palace, south-east view.

Fig. 9 Potlogi Palace, north-west view.

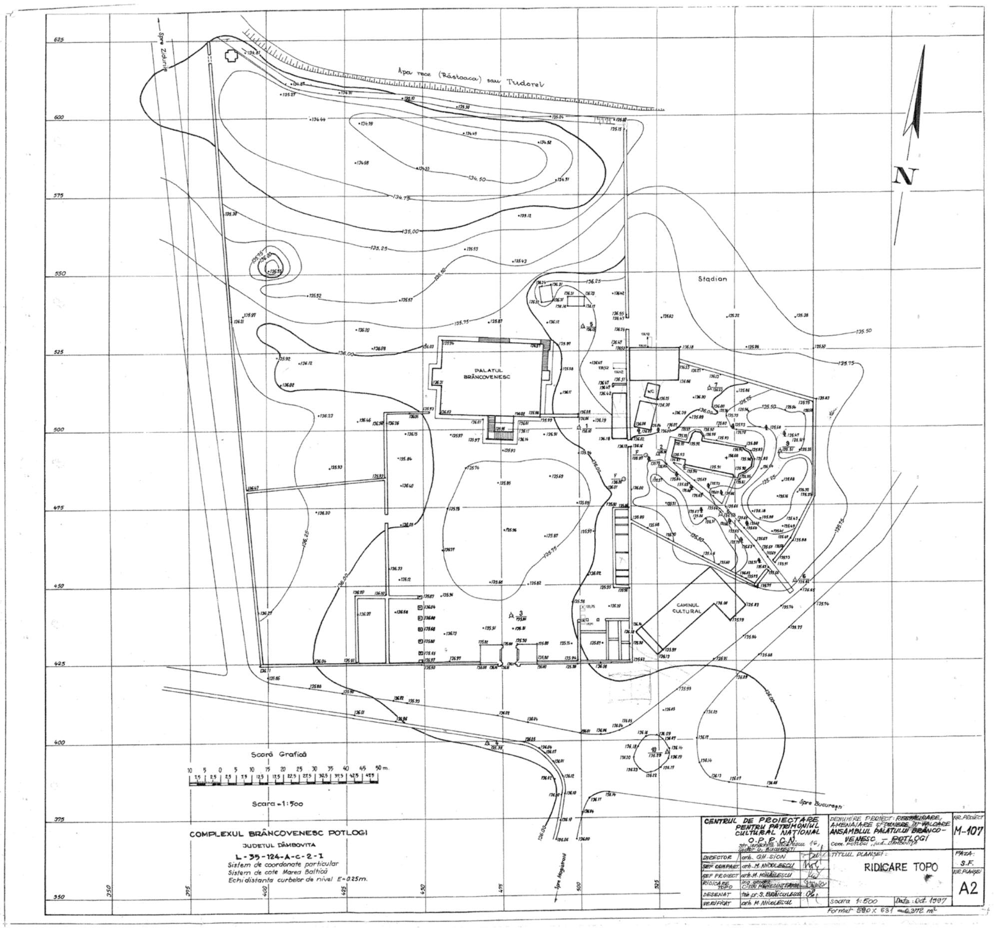


Fig. 10 Planimetric view, 1:500 scale, equidistance between the contour lines 0.25 m.

This paper presents the results of the first metric survey which was carried out in July 2011, on the occasion of a first workshop held in Romania, in which students of both the Gabriele d'Annunzio University of Chieti-Pescara (Italy) and the Ion Mincu University of Bucharest (Romania) participated.

The building presents a seemingly regular geometrical shape, but in reality the structure shows in many details a complex structural pattern, which is due, in part, to various restoration interventions over time. During the first phase of the survey only some parts of the building were examined in order to verify its structural conditions, namely: the fronts (with particular regard for the computation of the inclination of certain wall parts); the system of vaults of the main rooms located on the first floor; the shapes and building techniques and material conditions of the vaults in the large room with central pillar located in the basement.

Fig. 11 Potlogi Palace, entrance.

Fig. 12 Potlogi Palace, interior.

Structural Problems

The large vaults of the rooms located on the *piano nobile* show visible signs of cracks. A geometric study of the crack pattern was carried out as part of the pathology of the structural behaviour of the building. In order to assess whether the cracks could represent a potential cause of instability, it was deemed necessary to investigate in 3D the whole structural system of the main elements (walls, arches, vaults, pillars) that play a determining role in the static equilibrium of the building. The anomalies of the building, detected using a 3D digital model, could help researchers to arrange a monitoring plan of the relevant parts of the structure. Laser scanning techniques allowed to quickly build a digital 3D model with a high level of detail. Topographic and laser scanner surveys were useful to investigate relevant structural problems. The data gathered during the surveys were converted into a 3D polygonal surface (mesh). This numerical model was then used to investigate the structural aspects of the building, so that a diagnosis on the status of the building could easily be effectuated.

Survey Campaign

The survey campaign was planned with the goal of obtaining an accurate 3D model that could yield measurements, plans, profiles, sections and orthophotos on a 1:50 scale. Profiles and sections (directly obtained by slicing the 3D model) were needed to highlight and evaluate the inclined wall.

Modern high-definition laser scanning is able to generate 3D models with millions of points of the surveyed building. The recent development of laser technology finds significant applications in terrestrial scanning systems. These instruments collect point clouds with reference fields of almost panoramic views and make use of sophisticated servomechanisms for the management and control of micro-movements. The point clouds are organized in a matrix that contains the spatial position of these points, the colour information (RGB), and the reflectivity level of surfaces. The acquisition time for a panoramic scan (the one used for the measurement campaign is 360° × 305°) is about ten minutes. It provides a sampling of very high density. The 3D model is then formed by the appropriate aggregation of the various point clouds. The scan locations must be selected to offer the widest visibility of the surfaces of the object of interest, minimizing the areas that are occluded or in the shade. Problems related to occlusion and visibility represent, in fact, the main cause for lack of information and may lead to gaps in the point clouds.

The survey process was organized according to the following procedure, which can be subdivided in three subsequent phases of operations:

1. Data acquisition: Survey plannig, field operations
2. Data management: Data preparation, data registration, data processing
3. Quality control and delivery

Description of the Building

The building, rectangular in shape, has four levels, and is composed of a total of 28 rooms. In the basement there is a single large room with four vaults and a central pillar; the ground floor consists of ten rooms; and the main floor has fifteen vaulted rooms. The attic, a complex structure made of wooden lintels, visible in the 3D reconstruction (fig. 6), will be studied in the next measurement campaign. The building is approximately 32 m long, 23 m wide and 17 m high (from the ground floor up to the top of the roof). The perimeter wall is 9 m high. As far as the measurement campaign is concerned, the area surrounding the building is basically unobstructed as it does not include the presence of trees or other obstacles that could cause occluded areas in the scan data.

3D Preliminary Quick Modelling

Starting from available paper plans and sections at scale 1:50 (figs. 13–16) it was possible to generate a simplified 3D model of the building. This was made to facilitate the operations of the on-site survey campaign via a simple operation of raster-vector transformation based on the extrusion of closed polylines in order to obtain spatial information that is simple to handle in AutoCAD. This quick modelling exercise allows an initial understanding of the volumes, the surfaces and the positions of the apertures. The quick 3D model obtained from 2D orthographic views was very useful in designing and distributing the planar and spherical targets, and in choosing the most suitable positions of the scan points.

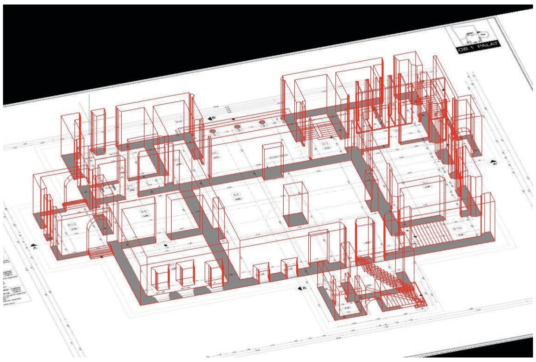


Fig. 13 Axonometric view of the model (wire frame).

Fig. 14 Axonometric view of the model (shaded).

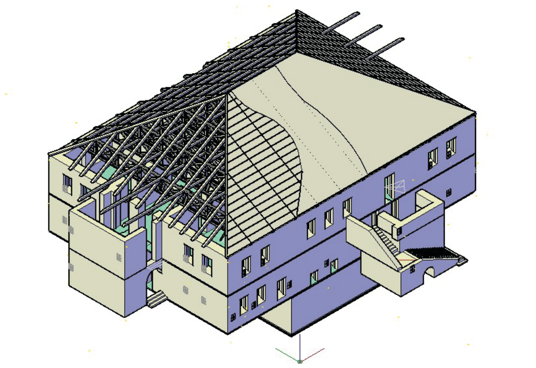


Fig. 15 Axonometric view of the whole solid 3D model.

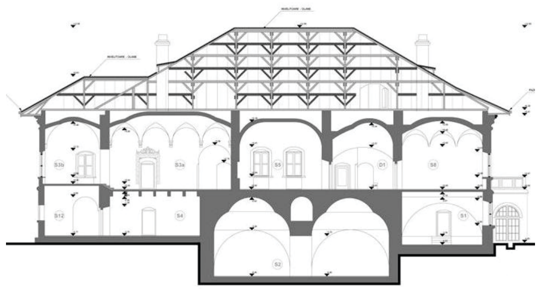


Fig. 16 Longitudinal section (available drawing) used to realize the row solid 3D model.

The 3D reconstruction (fig. 15) allowed us to create a model based on the available original drawing and with the help of photographs taken at the initial stage of the measurement campaign. The wooden roof structures have also been digitized and they can be shown in AutoCAD, either together with the roof covering (tiles, lead, etc.), or without the covering so as to display the rafters and trusses.

Instruments and Software

A Leica reflectorless total station TCR407 was used to set up the closed polygonal reference system (figs. 19, 22, 23) and to coordinate the target points (natural and artificial) around and on internal surfaces of the building. The laser scanning was conducted using a Faro Focus3D, a mid-range scan phase-based measurement system, with a stated range of 120 m. The scanner has an integrated

2-megapixel colour camera that is coaxial with the laser. It produces a 70-megapixel colour overlay using 84 photos to cover the field of view (360° × 305°). The collected data are stored on an SD card. Thanks to the compact size and light weight of the unit it was simple to transport by plane or car and easy to operate in difficult access conditions (staircases, narrow spaces). The Focus3D uses spherical targets (fig. 18) in addition to planar targets. FARO's Scene software automatically detects the sphere targets and registers multiple setups together.

The completeness of 3D point clouds represents a secure advantage over other sources of geometric information, but contrasts with the complexity of the management of millions of points; therefore the choice of the software used for processing the point clouds plays an essential role in laser scanning techniques. We used Leica Cyclone to process the external laser-scan data, FARO's Scene to align and register the internal scans, Rapidform XOR to extract from the 3D model the cross-section polylines and export them in DXF file format. Drawing up the elevations, plans, sections and final CAD drafting was completed with AutoCAD.

Fig. 17 3D indoor laser scanner survey operation.

Fig. 18 3D outdoor laser scanner survey operation.

The external and internal surfaces of the building were surveyed using topographic and laser scanning methods. In order to arrive at a precise geometrical correspondence between the data collected in each measurement system, a preliminary topographic survey was carried out. The topographic survey provides the definition of the reference system that is the basis for all the observations made, in addition to being the support of the laser scanning survey.

Topographic Network

The network consists of 12 vertices: 6 external ones, materialized by topographic nails, and 6 internal adhesive targets, which can be easily removed without damage to the surface. The measurement of the resulting closed traverse of 230 meters length has been carried out by means of a Leica TCR 407 total station.

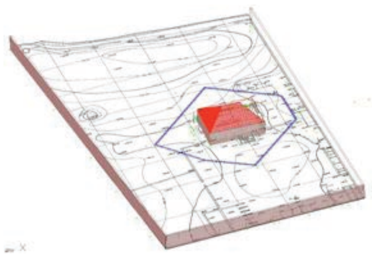


Fig. 19 Axonometric view of topographic network superimposed on map of environment.

Fig. 20 Total station set up.

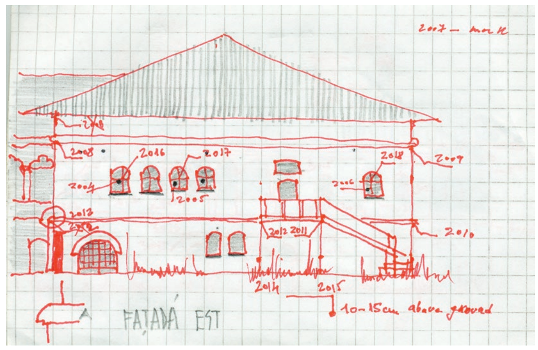


Fig. 21 Sketch traced during the topographic campaign.

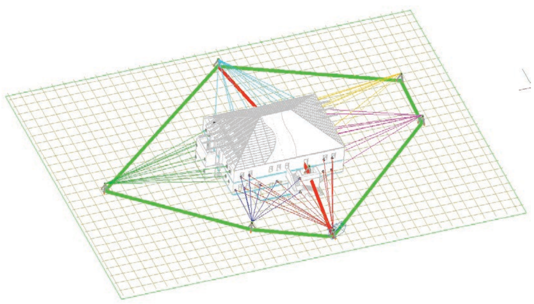


Fig. 22 Axonometric view of the network (grid spacing 3 m).

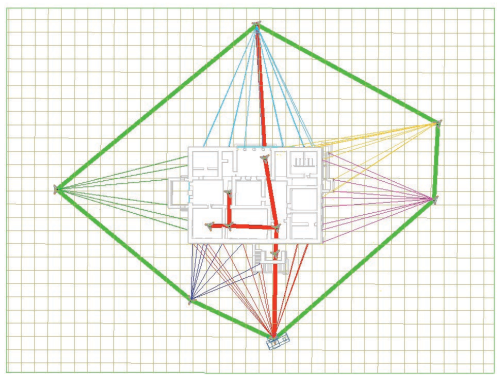


Fig. 23 Planar view of the Potlogi Palace, showing the layout of the geodetic network grid spacing 3 m. The green polyline shows the connections between the external vertices. In red the connections between the internal vertices.

In the second stage (which will be executed in July 2012), thanks to static GPS measurements, the local network will be linked with two points of the national reference system.

The point cloud acquisition phase is strongly conditioned by the shape, the dimensions, the required level of detail and the expected precision. In our case the scale of the final delivery material is 1:50.

Scale	Effective point density	Precision of measurement
1:50	5.0 mm	± 5.0 mm

Fig. 24 Relations between scale, point density and precision of measurements.

Taking into account that the beam width of the measurement equipment shall not be greater than the double of the effective point density and that the expected precision has also been established, we can define the operational range of the measurement operations, the setting parameters and the scan points.

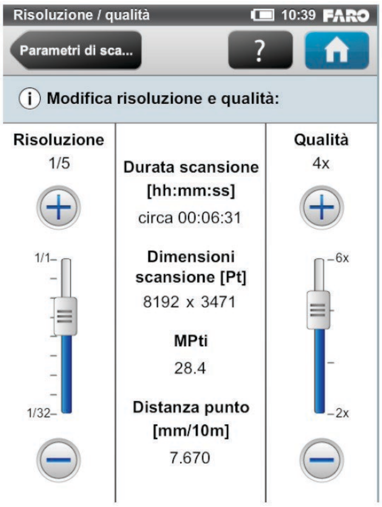


Fig. 25 Focus3D, setting of parameters on a touchscreen, quality and resolution panel.

Scan Point Planning

Care was taken to plan the standpoints of the scanner in order to obtain a high level of overlap between each scan and to ensure the appropriate data resolution, thus facilitating the subsequent drawing task. The individual scanner setups were positioned, where possible, at equal distances from the surfaces of the building and from each other; 28 scan points were placed: 12 around the building (fig. 26) for the definition of the fronts, 8 in the rooms of the basement and ground floor, and 8 on the main floor (fig. 27).

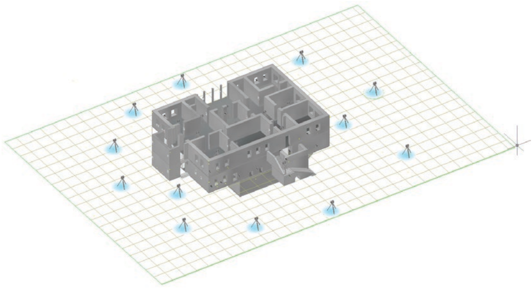


Fig. 26 Axonometric view of the model of Potlogi Palace, with layout of external laser scanning standpoints, grid spacing 3 m.

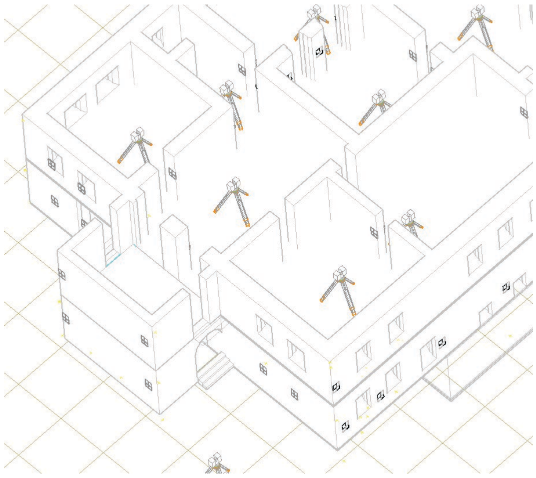


Fig. 27 Axonometric view of 3D digital model, with layout of internal scanning standpoints and planar target network.

Data Management

The data set gathered during the survey campaign was stored into a database application that enables the following data processing phases. The scans were registered using homologous points finalized to obtain a complete 3D digital model of the building (interior and exterior). The targets, detected automatically by laser scanner, were surveyed with a topographical station. Using coincident points it was possible to roto-translate the point cloud model into a topographic network and so to manipulate the model into an oriented 3D digital workspace. The set of the oriented scans were merged into a single point cloud model in order to remove overlapping areas. The entire point cloud model was broken down into several parts; each part was filtered to reduce noise, decimated, and then converted into a polygonal model. The polygonal models were handled using reverse engineering applications in order to obtain measurable sections and 3D views that are able to represent the shape and the state of conservation of the building (figs. 34, 37).

First Results of the Survey

The following illustrations show some examples from the first phase of the survey.

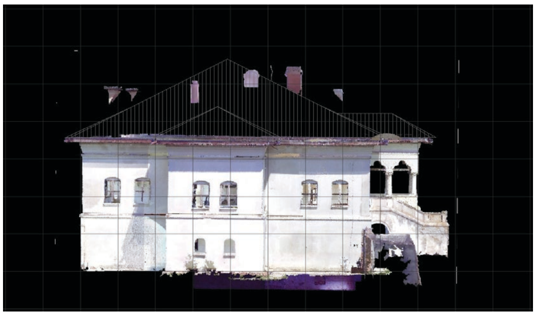


Fig. 28 West elevation (grid spacing 3 m).

Fig. 29 South elevation (grid spacing 3 m).

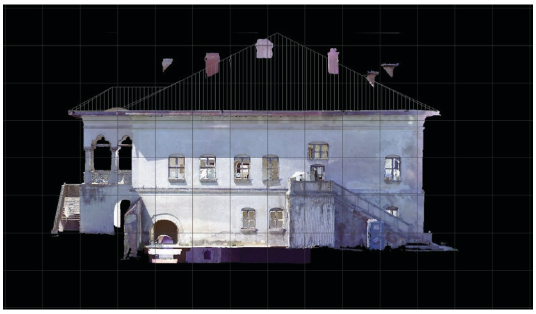


Fig. 30 East elevation (grid spacing 3 m).

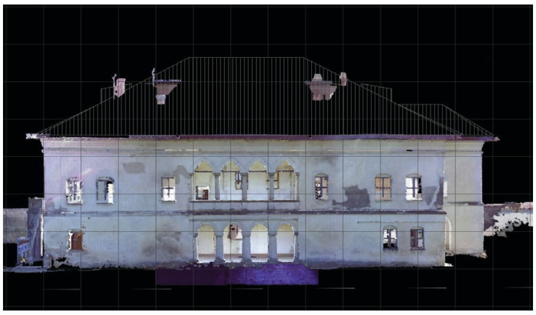


Fig. 31 North elevation (grid spacing 3 m).

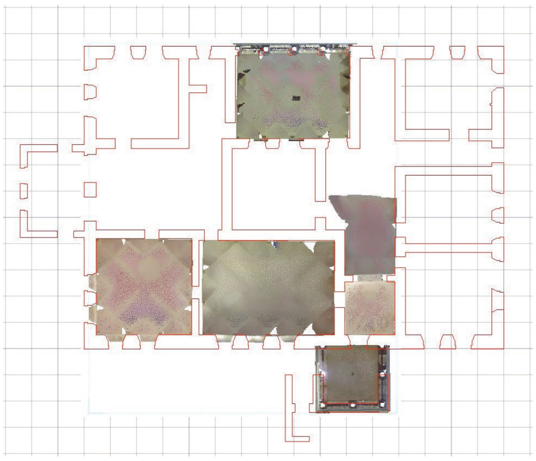


Fig. 32 Plan of the investigated vaults of the first floor.

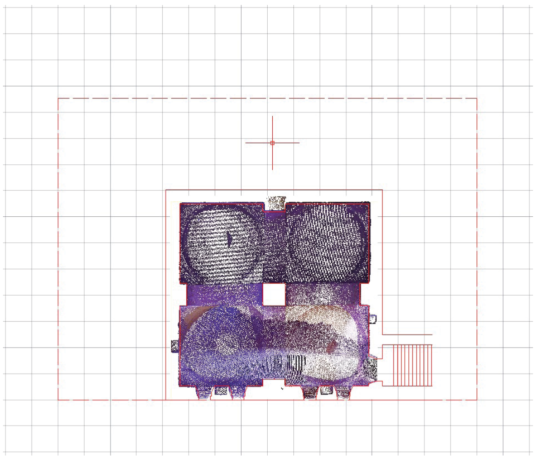


Fig. 33 Plan of vaults at the basement.

3D Meshed Model

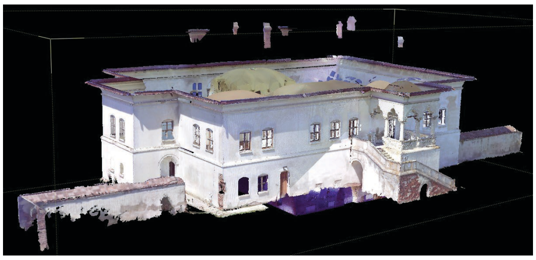


Fig. 34 3D meshed model, south-west view.

Fig. 35 Potlogi Palace, south-west view.

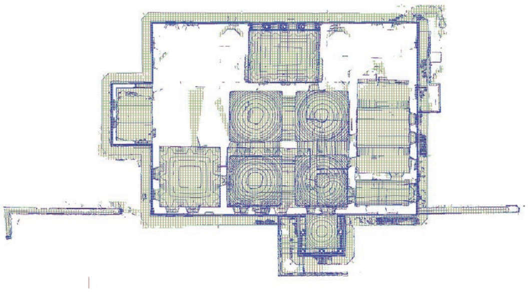


Fig. 36 Plan view of the set section (distance between sections 0.25 m).

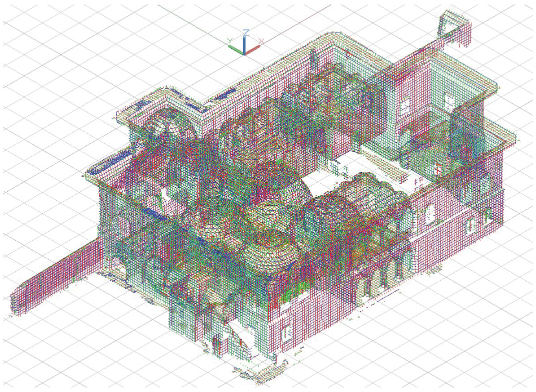


Fig. 37 Axonometric view of the cross-section set.

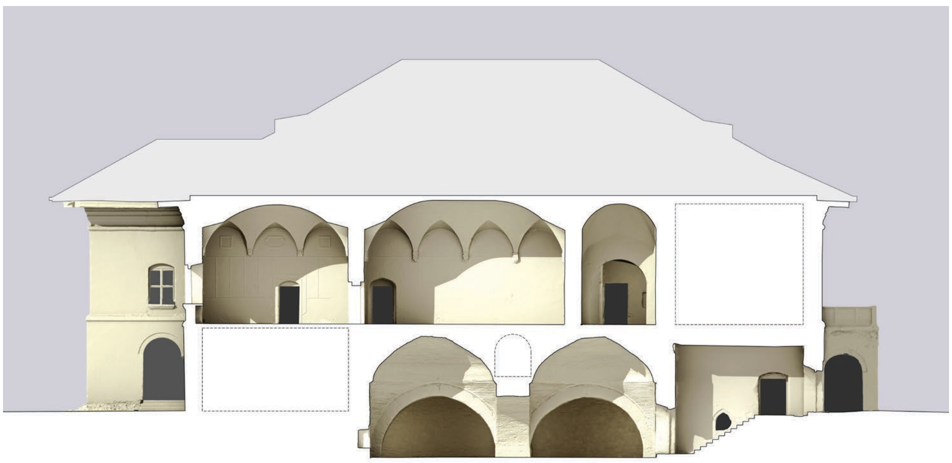


Fig. 38 Sectional elevation.

Fig. 39 Internal view of the loggia; high point density gives detailed representation of individual features.

Conclusions

The first results of this inter-university and interdisciplinary experience led to the creation of a 3D model of Potlogi Palace. The model, characterized by high accuracy and fine details, allowed the historical building to be studied remotely, saving travel expenses and time, and enabling Italian and Romanian scholars to study, plan decisions and interventions, and prepare the programme of investigations to be carried out in the next measurement campaign.

Acknowledgements

The authors wish to thank: arch. Petru Mortu, arch. Daniel o Gabriel Panasiu and arch. Emilia Tugui for the support during the data acquisition stage; arch. Sergio Di Tondo for the precious collaboration during the data processing phase; Donato Palumbo and Vassilliki Goula; Geocart Pescara for providing laser scanner Faro FOCUS3d CAM2 and software Faro Scene 4.8; UnoCad Vicenza for the use of software Rapidform XOR; Leica Geosystems Rome, Cyclone software, for assistance and collaboration in data processing.

Bibliography

Alba, Mario and Scaioni, Marco, 'Comparison of techniques for terrestrial laser scanning data georeferencing applied to 3D modelling of cultural heritage', *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 36 (2007) 5/W47.

Binda, Luigia, Mirabella Roberti, Giulio and Guzzetti, Franco, *San Vitale in Ravenna: a survey on materials and structures*, IASS-MSU International Symposium (Istanbul, 2000), pp. 89-99.

Bonollo, Monica, *La costruzione del vedere. Simulazione Visiva, Realtà Virtuale e Costruzione del Mondo* (Vicenza, 1992).

Brătuleanu, Anca, *Romanian Princely and Nobiliary Courts. The 17th and 18th century Walachia* (Romanian-English edition) (Bucharest, 1997).

Brătuleanu, Anca, 'L'architettura del giardino Veneto e il giardino romeno (XVII e XVIII secolo)', *Dall'Adriatico al Mar Nero: veneziani e romeni, tracciati di storie comuni*, (Rome, 2003), pp. 203-212.

Bryan, Paul, Blake, Bill and Bedford, Jon, *Metric Survey Specifications for Cultural Heritage* (D. Andrew Editor, 2009).

Bezoari, Giorgio, Selvini, Attilio, Borsa, Marco, Mataloni, Giovanni, 'Il castello di Somma Lombardo. Diverse modalità di rilevamento e rappresentazione', *Recupero e Conservazione*, 95 (2011).

Cantoni, Roberto, Vassena, Giorgio and Lanzi, Claudio, *Integrazione tra Laser Scanning e metodologie di rilievo tradizionali nella ricostruzione 3D*, proceedings National Conferece ASITA, (Perugia, 2002).

Carbonara, Giovanni, *Avvicinamento al restauro* (Napels, 1997).

Cerasi, Maurice, 'Città e architettura nel Settecento', *Rassegna*, 4 (1997), pp. 36-52.

Colombo, Luigi, 'Tecnologia e Tecnica nel Laser Scanning Terrestre. Annotazioni per i Beni Culturali', *Archeomatica*, 9 (2011).

Cunico, Mariapia, *Il giardino veneziano, La storia, l'architettura, la botanica* (Albrizzi, 1989).

D'Avino, Stefano, 'Il rilievo computerizzato come modello interpretativo per il restauro', *Contributi*, 4 (1997), pp. 25-30.

D'Avino, Stefano, 'Reale e virtuale. Osservazioni su un complesso rapporto e sue implicazioni nel restauro', in *Inserzioni Disegni*, ed. Carlo Mezzetti (Rome, 2007), pp. 77-87.

De Seta, Cesare, 'Maniere e artifici per narrare l'arte', *Op-cit: rivista quadrimestrale di selezione della critica d'arte*, 125 (2006), pp. 15-21.

Djindjian, François, 'Nouvelles tendances méthodologiques dans le traitement and l'information en archéologie', *Archeologia e calcolatori*, 1 (1990).

Eloueini, Ammar, *L'architecture virtuelle: une nouvelle frontière de l'espace* (Paris, 2002).

Forte, Maurizio and Guidazzoli, Antonella, 'Archeologia e tecniche di eidologia informatica', *Archeologia e calcolatori*, 3 (1992), pp. 38-77.

Ghica Budeşti, Nicolae, 'Evoluţia arhitecturii în Muntenia şi Oltenia', *Buletinul Comisiei Monumentelor Istorice*, 4 (Bucureşti, 1936).

Gregory, Tullio, 'Nel mondo semantico del virtuale', *IF rivista della Fondazione IBM*, 1 (1997).

Guerra, Francesco, Balletti, Caterina, Stevanin, Cecilia and Vernier, Paolo, '3D geometric analysis of the facades of gothic buildings in Venice: examples of 3D modeling', in *Proceedings Italy – Canada 2005 2nd Workshop 3D digital Imaging and Modeling application of: Heritage, Industry, Medicine & Land* (Padua, 2005).

Il giardino veneto, ed. Margherita Azzi Visentini (Milan, 1988).

Maldonado, Tomas, *Reale e virtuale* (Milan, 1992).

Masiero, Roberto, 'I linguaggi dell'autenticità', *ΑΝΑΓΚΗ*, 4 December 1993, pp. 9-13.

Monti, Carlo, Fregonese, Luigi, and Achille, Cristiana, 'Laser scanner application on complex shapes of architecture. Profiles extraction processing and 3d modelling', in *Proceedings of the ISPRS working group V/6 (International archives of photogrammetry, remote sensing and spatial information sciences)*, XXXIV, 5/W10, (Tarasp-Vulpera, 2003).

Santana Quintero, Mario, Lerma, Jose Luis, Heine, Erwin and Van Genechten, Björn, *Theory and practice on Terrestrial Laser Scanning* (Valencia, 2008).

Vecchi, Benedetto, *Nell'ipertesto della realtà* (Milan, 1997).

Illustrations

Fig. 1 Popescu, M., 'Oltenia în timpul stăpânirii austriece', *Buletinul Comisiei Monumentelor Istorice*, iulie-septembrie 1926, p. 105, drawings made by the Austrian Engineer Johann Weiss in 1728-1731.

Fig. 2 Academia Română, the Prints Collection.

Fig. 3 Survey drawing, Drăghiceanu, V., *Buletinul Comisiei Monumentelor Istorice*, 1910; photo author, 1980.

Fig. 4 Photos Liviu Brătuleanu, Horia Moldovan, 2011; drawing survey, Department of History & Theory of Architecture and Heritage Conservation, 'Ion Mincu' University of Architecture and Urbanism.

Fig. 5-39 Virtual models developed by Laboratory of Topography, Department of Architecture, University of Chieti-Pescara.

[1] Ghica Budeşti 1936.

[2] For the Italian influences, see the bibliography.

[3] This affirmation is the result of on-site research made by the author at Potlogi and Istanbul (edifices built before the end of the seventeenth century).

[4] Bonollo 1992, p. 95.

[5] Forte 1992.

[6] See Carbonara 1997, p. 474.

[7] Forte 1992.

[8] See also Torsello 1999.

Revisiting the Past through Virtual Reconstruction: The Case of the Grand Monuments of Paharpur, Bangladesh

Md Mizanur Rashid (International Islamic University Malaysia)

Hafizur Rahaman (National University of Singapore)

This study aims at developing a virtual model of the lost architecture of the Buddhist Monastery of Sompur Mahavihara in Paharpur, Bangladesh. The eighth-century monastery is one of the earliest examples of monumental architecture in Bengal and in 1985 its ruins were listed as a UNESCO World Heritage Site. From the very discovery of its ruins the monument drew the attention of architectural historians of South and Southeast Asia because of its unique architectural features and strategic location in space and time. The monument's architecture, however, is scantily documented, because after a millennium of amnesia first-hand resources are unavailable. The architectural historian's main sources are therefore the fragmentary archaeological remains, literary evidence, and epigraphic records. This study attempts to develop a virtual model of Sompur Mahavihara that can accommodate different contesting narratives regarding its architecture. It looks into history in a dynamic way and uses virtual reconstruction as a flexible tool to reconstruct the lost monument.

The aim of this paper is therefore twofold. First, it develops a methodological framework for retrieving and commemorating both tangible and intangible aspects of the monastery, perusing a critical theoretical construct, and then applies this knowledge to elaborate a conjectural virtual reconstruction. Second, it presents an online interactive platform that was created to collect public comments and contributions on the past culture and history of Sompur Mahavihara, so as to reinvent and renew the previous model. We hope this participatory approach will minimize the distance between the people and the heritage object and will engender a new way of exploring, experiencing, evaluating and appreciating heritage buildings.

The Monument

After their discovery in the early twentieth century, the ruins of the Sompur Buddhist monastery (Sompur Mahavihara) became the focus of attention for architectural historians of Bengal. The megastructure is considered a landmark in Bengal's architectural history for two main reasons. First, it marks an important transition from an unintentional and vernacular mode of architecture to the most conscious, symbolic and metaphoric mode. Second, it symbolizes a particular era in which Buddhism had its last stronghold in India under the royal patronage of the Pala kings, before gradually transforming into a more ritualistic practice than the philosophical doctrine preached by Buddha, which is known as neo-Buddhism or Tantric Buddhism.[1]

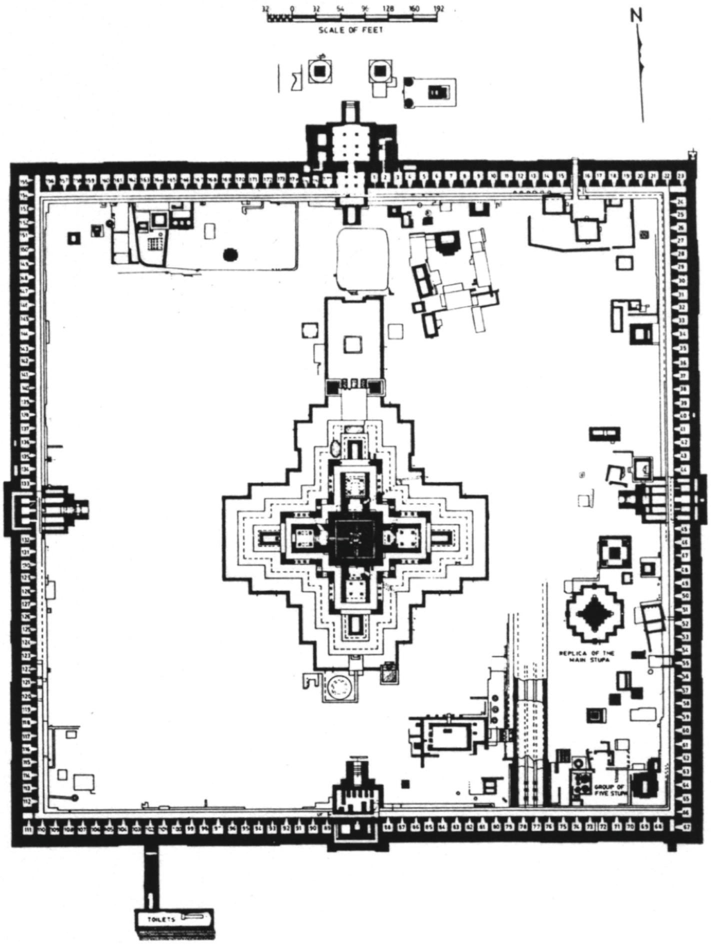


Fig. 1 Excavated floor plan of Sompur Mahavihara showing the organization of monastic cells and the central structure.

The most striking architectural feature that distinguished Sompur Mahavihara from other Buddhist monasteries in South Asia is the central cruciform structure (fig. 1 and 2). Hitherto most debates have centered on the missing superstructure, its layout and its architectural details. The ruin of the structure rises upward in a tapering mass of three receding terraces, reaching a height of 23 meters. Each terrace has a circumambulatory passage around the monument. At the top-most terrace (of the existing ruin) there were four antechambers on the projecting arms of the cross. The overall design of this complicated architecture is centered on a hollow square shaft that runs down from the present top of the mound to the level of the second terrace.

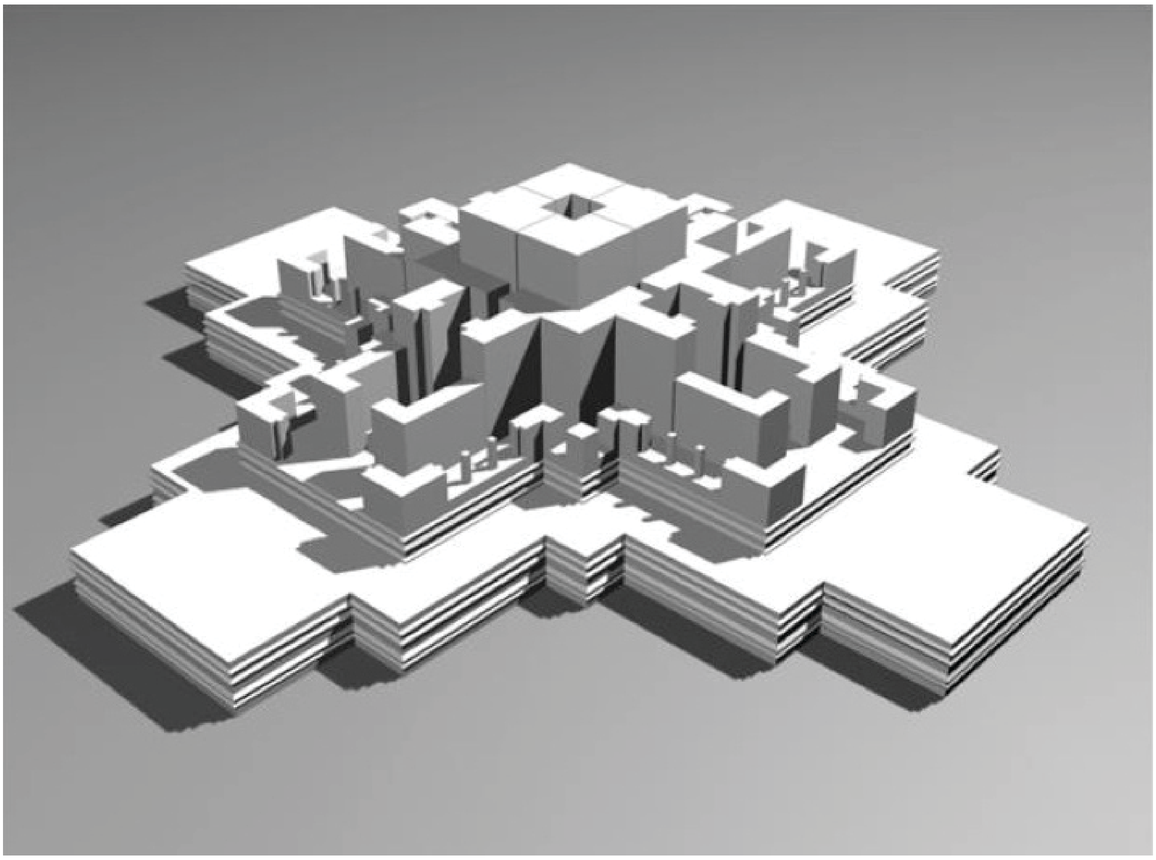


Fig. 2 Reconstructed model of the central structure.

Sompur Mahavihara is certainly the most studied historical monument in Bengal. The three-dimensional articulation of the missing superstructure of the central edifice remains at the center of the debate and several scholars have attempted a theoretical reconstruction.[2] The nature and extent of these earlier studies are no longer satisfactory, however, because the researchers did not have access to a comprehensive architectural documentation of the monument. The tacit historical record and the fragmentary archaeological remains (which are mostly at foundation level) have further confounded the situation. As a consequence, most of the work done so far is limited to archaeological excavations and to studying the artifacts from an archaeological perspective. Hence the history of Buddhist architecture in Bengal remains largely to be written.

Historical Amnesia

After the fall of the Pala kings in Bengal in the twelfth century, Buddhism in South Asia declined. The withdrawal of the royal patronage from the monasteries endangered the religion. The 'Sangha' (community of monks) and monastic life were the foundation of Buddhist religious practice,[3] which started to wane after the decline of the monasteries. In the thirteenth century the Afghan invaders gave the final blow by destroying Hindu and Buddhist religious edifices, either out of missionary zeal or to acquire building materials for the construction of mosques.[4] This obliteration of the monasteries ultimately uprooted the Buddhist 'Sangha', forcing the monks to flee. Consequently, Buddha and Buddhism were totally forgotten in the land of their birth.

The rediscovery of the history of Buddhism began with British colonial officers who were informed about Buddha and his birthplace by officials from Myanmar and Sri Lanka, where Buddhism was alive at that time.[5] Sir Alexander Cunningham (1814-1893) in particular did archaeological excavations in places like Sarnath and Bodhagaya, which were mentioned in Sri Lanka texts. Eventually these attempts took a much more concrete shape when two Chinese travelogues, Fa Xian's Records of the Buddhist Countries and Xuanzang's Records of the Western Regions, were translated into English. The latter gave a vivid description of Buddhist religious edifices, including details such as their location, size and shape. Cunningham used these two Chinese travelogues as a guide to rediscover the Buddhist past of India. They helped to map out the Buddhist religious sites and to rediscover the history of their monuments, but in the absence of any other records Buddhist India was seen through their eyes only and as such rediscovered only partially. Later, other Chinese travellers, such as I-Tsing and Sheng Chi, who also recorded other examples of Buddhist architecture, were studied as well, but places that were not travelled and recorded by anybody still remained forgotten. More recent archaeological discoveries have revealed their physical existence but cannot retrieve their memories. Sompur Mahavihara is one of them. Although a significant monument in terms of size, shape, location and, most importantly, its mention in historical records, the narrative of its architecture remains discontinuous.

As already mentioned, the major problem today is how to reconstruct the past when sources are scarce, inconspicuous, and fragmentary. Lest Sompur Mahavihara remain a forgotten chapter in the history of architecture, we need to face this challenge. To confront this situation and to continue research on this monument, a pragmatic approach is needed.

From Constraint to Opportunity

Earlier attempts at reconstructing the architecture of the monastery have failed to offer a cogent solution. Though this seems due to the fact that sources are scarce and fragmented, we feel that the main problem is the absence of a scientific framework to collate all available sources. Though certainly difficult it is not impossible to build a continuous narrative of the monument's architecture depending solely on first-hand material. The paucity of tangible sources can also be turned into an opportunity, for the followings reasons.

First, the lack of material sources implies that there are no preconceived notions about the building process of the monument, which can therefore be studied from a very neutral point of view. It may not result in a very accurate understanding of the architecture itself, but at the same time lessens the risk of a wrong interpretation of the archaeological ruins. Especially for Sompur Mahavihara, where most of the architecture is missing, the problem can be looked at in a broader perspective and in a more flexible way, and the focus can shift from the product to the process.

Second, this situation makes it possible to accommodate earlier studies and rival hypotheses. The discrete approaches of these earlier works do not necessarily indicate a disjunction. Rather, they demonstrate a range of possibilities. Putting these together in one platform offering critical analysis may elucidate the problem. The aim is not to discredit these earlier assumptions, but to develop an integrated approach that embraces all possibilities. Eventually this can establish a theoretical framework for further study, by accepting, criticizing or refuting some of these earlier assumptions.

Third, the building is part of the region's material culture. This material culture is determined by different aspects, such as the tradition and world view of the people, the custom of reverence, symbol and rituals of expressing status, gender relationship, sepulchral tradition, and so on. These aspects can be seen as layers that overlap and mutually influence each other. Because of the amorphous nature of the religion, Buddhist religious architecture is very susceptible to changes of these cultural conditions. Hence discerning the layers that acted upon the monument will help to understand its architecture. This means looking into its history in a more dynamic way and using all the available tools. Information from different sources must be used to evaluate the problem of architecture in a much broader perspective.

Fourth, virtual modelling is a useful tool for multiple verification and criticism. The goal is not to produce a photorealistic reconstruction of Sompur Mahavihara, but to develop a method of evaluation and synthesis to conceptualize the form of the structure. Abstract drawings are more effective and better understood than highly realistic ones, as Osberg has shown.[6] Virtual reconstruction is to be applied at two levels. The first level is an exact visualization of the existing remains of the structure, to be used as the basis for further study. The second level involves a comprehensive process of evaluation and verification in order to generate a process of theoretical reconstruction using all the available information. Since the available material makes it difficult to come up with a single model for the central structure, our study may end up with several theoretical models based on different hypotheses. This process of theoretical reconstruction and interpretation of the available information is a continuous one. Elements not comprehended today can perhaps be understood in the future, provided that the underlying information is preserved.[7] Even corrections, criticisms and debates can be accommodated in successive reconstructions. This is perhaps the most flexible way to use all the available resources, including those that are apparently inconspicuous in nature.

Phase 1: The Beginning

Out of caution, no definite course of research was proposed at the beginning. The reason was the limited amount of sources as well as the blurred nature of the field. The initial framework was flexible and tentative. The strategy was to proceed in stages, starting from a broader framework and then gradually descending to the next levels one after the other. The inference deduced in one level determined what type of information should be looked for at the next level. Hence the overall framework got more concrete as the research progressed. A schematic diagram (fig. 3) compares the tentative framework and the actual course of the study. It gives a clear idea of the different levels of the actual study, their objective, findings and interrelationships. In a nutshell, this gradual research progression can be called a Historical Scan. Since the available information on the monument is scarce and fragmented, and since what exists today is also confabulated to some extent, it was necessary to scan all the sources for bits of information and then collate these together in a scientific way. The early stage of the scanning process focused on historical studies to define the purpose and use of the structure. The later stage scanned through all the historical resources to resolve the technicalities of the monument's theoretical reconstruction.

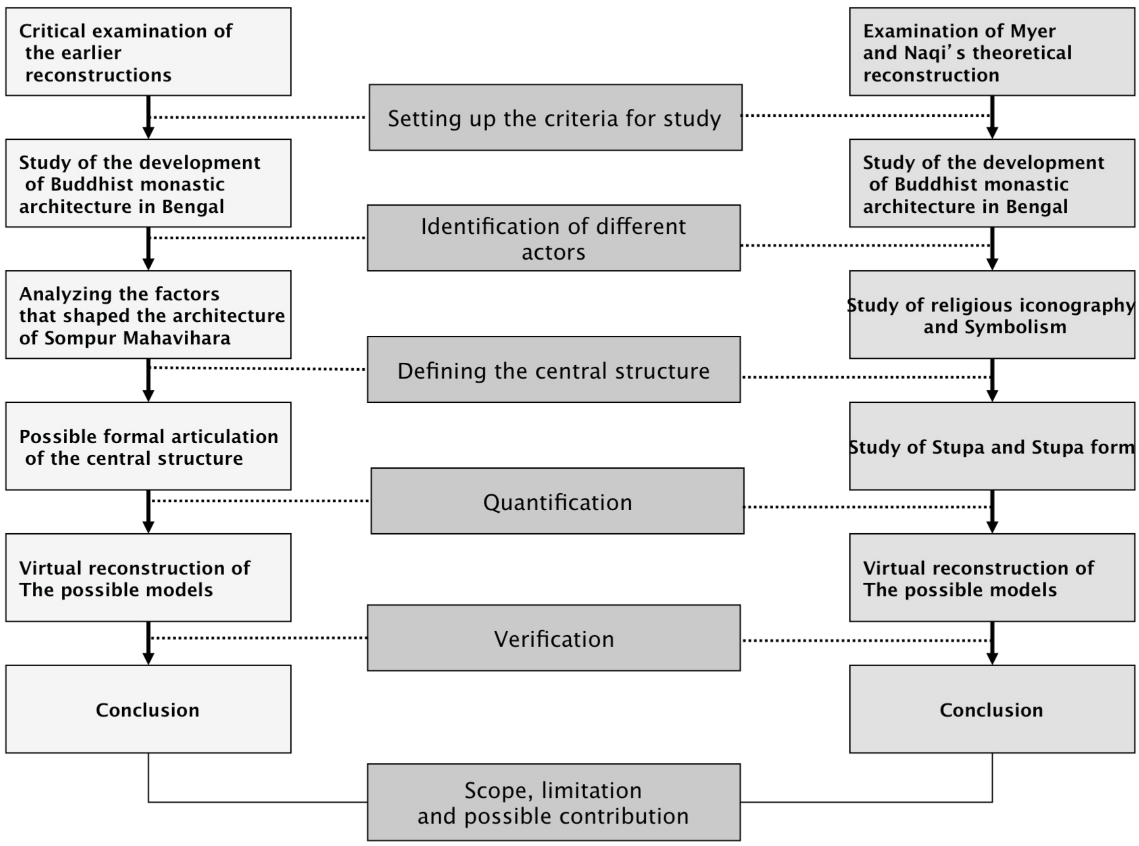


Fig. 3 A comparison between the initial research outline and the actual course of study.

Historical Scan 1 – Defining the Structure

The historical study focused on the process of resilience and assimilation through which the design of the monastery was conceived and materialized in this particular context of Bengal. First it unravelled the historical layers that combined to shape this particular form of architecture. Hybridized forms and shared architectural narratives were unique to the material culture of Bengal during the Pala period (8th-12th century). The study identified the historical processes of hybridization of the major layers and their diverse morphological outcomes. It further revealed that the architecture of this great monastery or Mahavihara was shaped by two factors: the overt effort to create a particular place with religious and symbolic meaning, and the existence at the core of a vernacular with a particular world view, culture, and attitude towards space. Accordingly, religious consciousness shaped the 'visible' superstructure, while underlying vernacular ideas defined the 'true' nature of the space. The earlier monastic architecture (Vihara) of Bengal, which adopted the morphology of traditional courtyard houses, was thus transformed into a more symbolic and metaphoric building. On the one hand, the highly esoteric and ritualistic nature of Tantric Buddhism embraced the principles of Mandala to plan and organize spaces and to determine the hierarchical relationships between them. On the other, the political zeal of the Pala rulers motivated the gigantic scale of the building as part of a grand scheme to demonstrate their power and hegemony.

After analysis and synthesis of these layers we deduced that the central structure of the monastic complex must be a manifestation of the Stupa, the most venerated of Buddhist religious edifices.[8] Before confronting the archaeological remains with the architectural characteristics of a Stupa, however, we had to perform a rigorous study of different types of Stupa, their transformation through time, and their possible manifestations in function of social and cultural factors. Finally we presumed that the central Stupa is not just a Stupa but a new type of Buddhist religious structure which evolved during this period and which is known as a 'Stupa-Shrine', a combination of a shrine with the superstructure of a Stupa.[9]

It is clear now that this unique type of 'Stupa-Shrine' was conceived to satisfy the religious, social and political aspiration of the time. Yet it is difficult to imagine that in a vernacular building industry, whose construction practice was based on using models or variations of models, some artisan came up with a unique cruciform design solely out of his own creativity. It is more likely that the final version of the design resulted from the reuse and modification of certain models to meet with the new religious and political demands.

How the designers arrived at this complicated design is a big question. A rigorous study of the available resources suggests two possible schemes. The first one (described in fig. 4 as Scheme A) is based on a typical late Mahayana Stupa with elongated drum, bulbous dome, and elaborated finials, with four Buddha statues seated on the four cardinal directions. The second one (Scheme B) is based on the archaeological discovery of a certain structure in which a conscious attempt to combine a Stupa and a shrine chamber is discernible.

It can therefore be concluded that the central structure was originally a 'Stupa-Shrine' and that the archaeological ruin on site was actually crowned with the Stupa superstructure.

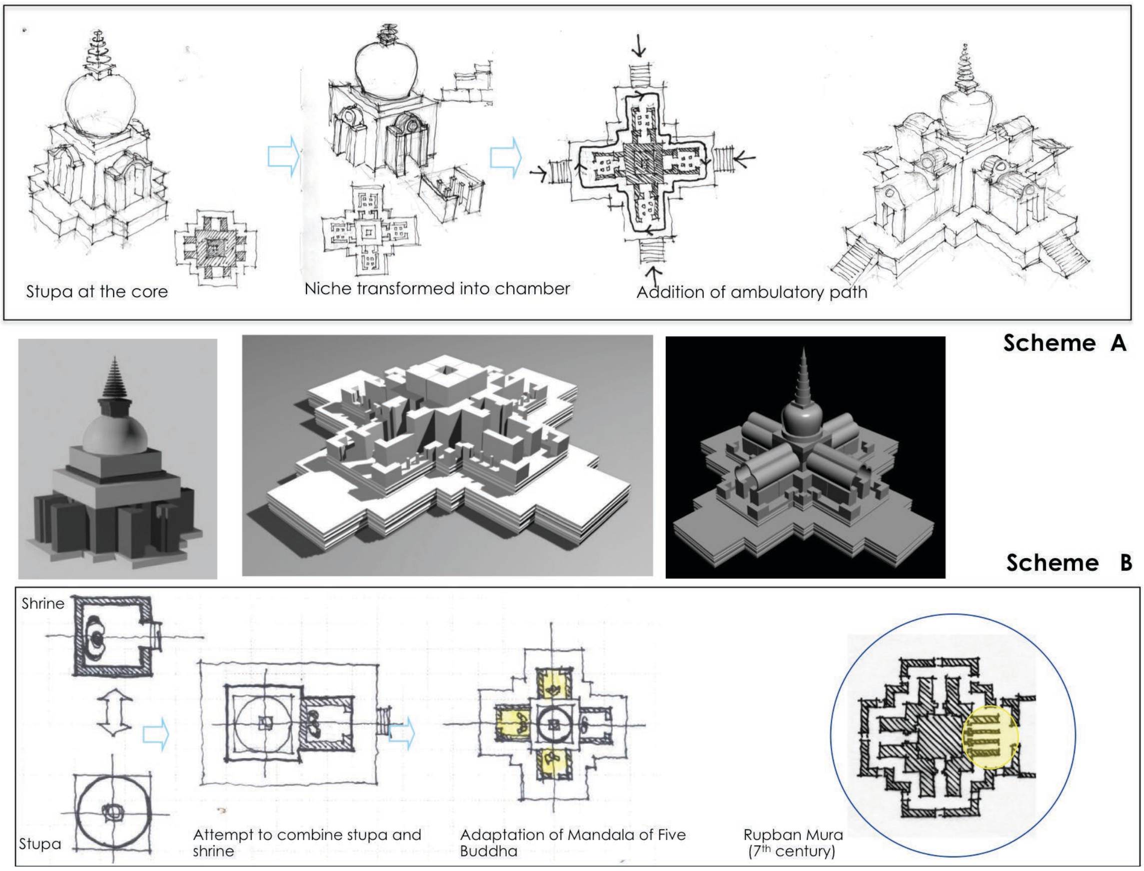


Fig. 4 Probable schemes for the design of the central structure. The three images in the middle are reconstructed views of the ruins (which are currently covered with soil) and its possible manifestation as stupa shrine (refers to the final product of both the schemes A and B).

Historical Scan 2 – Quantification and Virtual Reconstruction

As the primary objective was to reconstruct the structure virtually, some quantifiable data were needed. From the ruins of the central structure the two-dimensional layout and dimensions could be discerned. Its precise geometry suggests the presence of a relationship between the two-dimensional layout and the three-dimensional construction. Identifying this relationship may help to reconstruct the structure. This was attempted in two ways. A metrological study of Stupas with formal affinities to our case study was carried out to understand the proportional system, and historical records were scanned for information on the metrology and proportions of the Stupa. Here the ninth-century manual of *Kriya Sangraha* of Kuladutta[10] was very helpful, as it vividly describes the dimensions, forms and proportions of the four types of Stupa to be built for worship (fig. 5).

Combining the findings from both these sources helped to come up with a possible three-dimensional reconstruction of the monument.

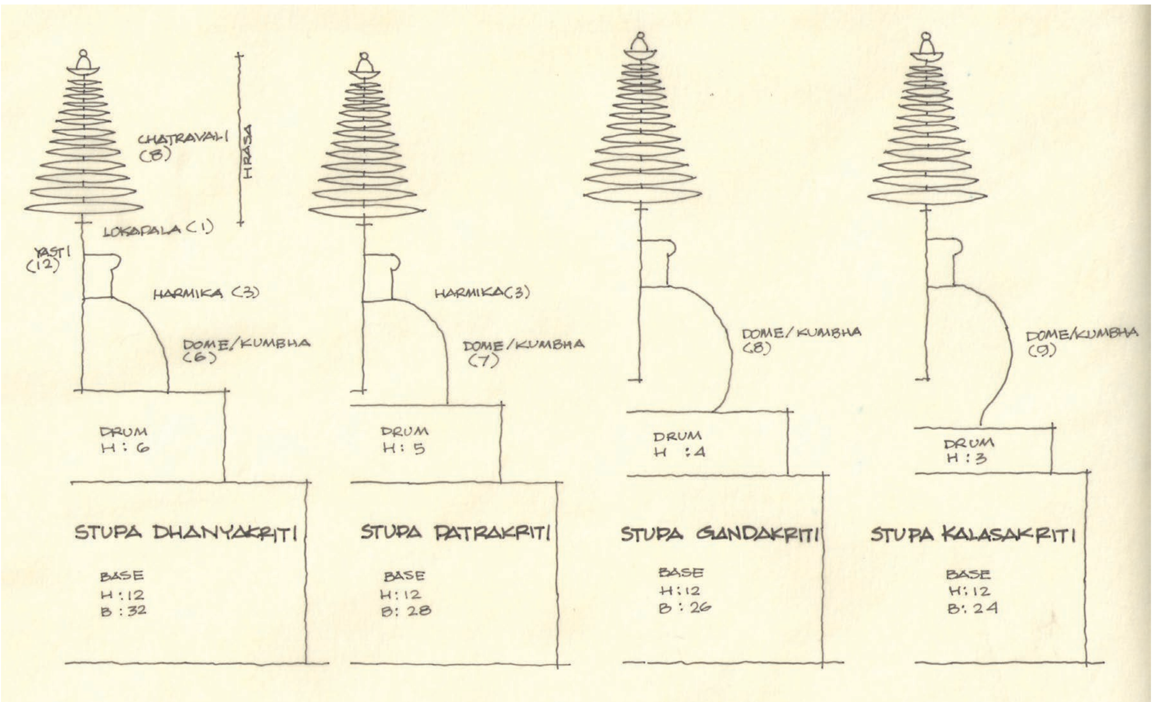
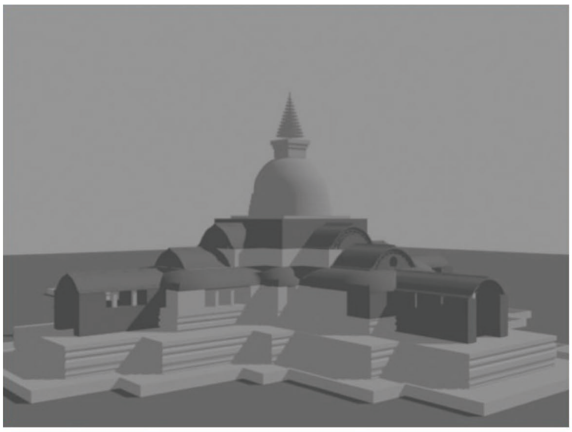


Fig. 5 Different types of stupas and their proportioning system after *Kriya Sangraha*.

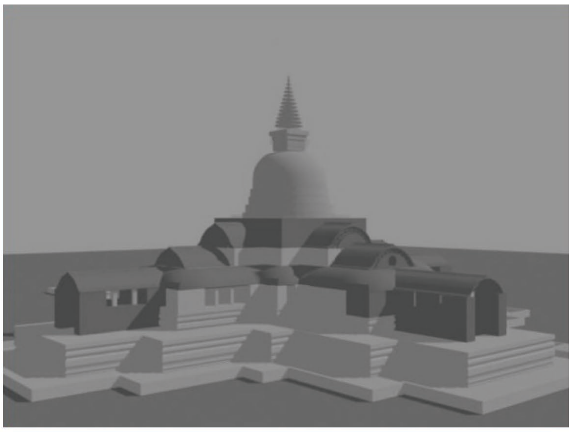
Nevertheless, this study does not necessarily reveal the exact proportioning system that was applied in the monument of Paharpur, since each Buddhist structure was treated as an individual case and highly influenced by geographical and cultural factors. Despite that limitation this study provided a frame of reference to develop a concrete shape of the Stupa superstructure. Four types of Stupa superstructures were reconstructed and then verified with the actual archaeological remains on site (fig. 6). The reconstructed Stupa form that conforms best to the archaeological ruin of Sompur Mahavihara is possibly very close to the one that was actually built (fig. 7).

Virtual reconstruction was adopted as the most flexible means to exploit all the available sources and to keep the research open for further verification. The first part of the study did not propose one particular 3D model for Sompur Mahavihara but examined various possibilities. These different models were compared with the archaeological ruins to identify the closest possible match. This process is ongoing, however, and has enough room to accommodate future criticisms and corrections.

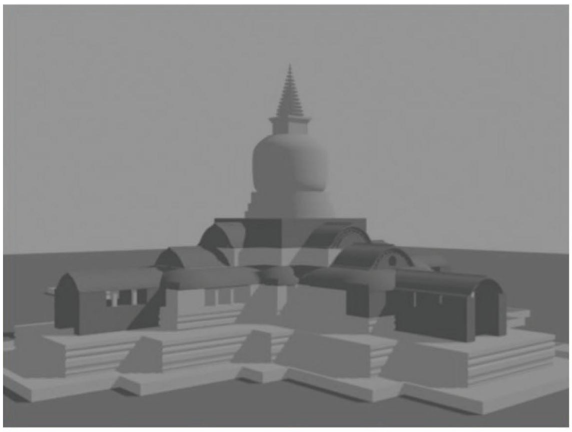
Because of the fragmentary nature of the available evidence there were some uncertainties in the study, but these gaps were filled by architectonic reasoning. This may not yield a definite solution, but it did shape the discourse, which before was amorphous. Now at least it is clear what kind of information is still missing and how it might change the form of the building.



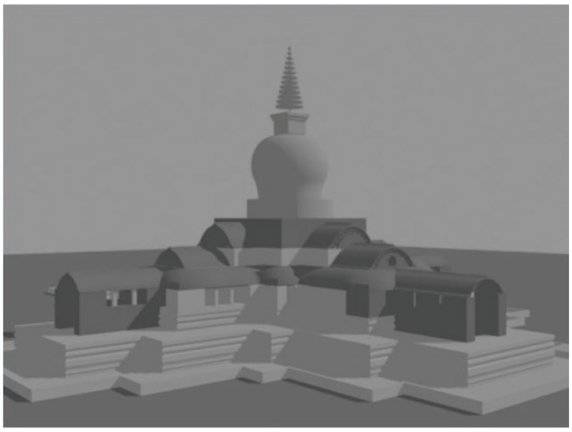
Stupa Dhanyakriti



Stupa Patrakriti



Stupa Gandakriti



Stupa Kalasakriti

Fig. 6 Reconstruction models of the central structure of Sompur Mahaviahara after *Kriya Sangraha*.

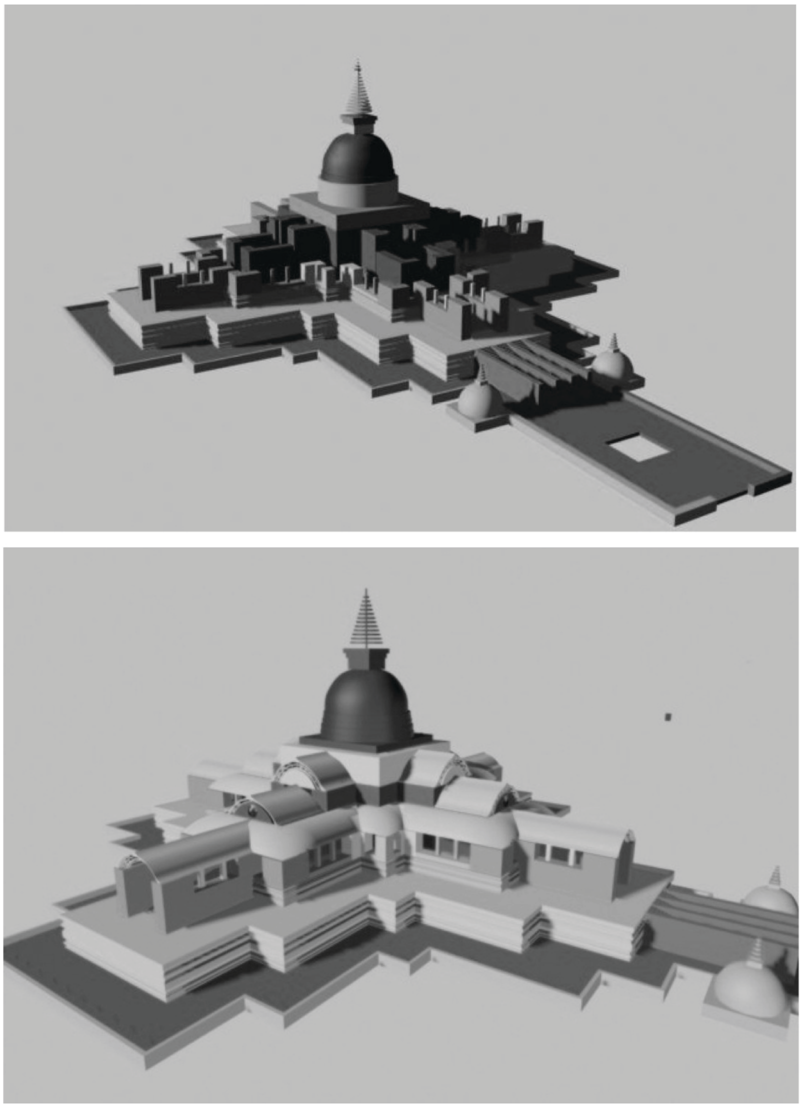


Fig. 7 Final Reconstruction model of the monument according to Stupa Dhayakriti with the closest match to the existing ruins.

All the available information was arranged in a systematic way for the next step of the study, the development of an interactive an open framework which invites feedback so as to refine the virtual reconstruction (fig. 8). The most important aspect of this framework is that it relies not just on architectural or archaeological sources, but adopts a cross-disciplinary approach. Any discovery in any discipline can be entered in this framework to see how it affects the three-dimensional form of the structure. It also shows future researchers what type of information they should look for and how this can help to understand the architecture of Sompur Mahavihara. The framework also demonstrates the scope for future refinement of the virtual model. Importantly, it is flexible and can be modified in the future if necessary.

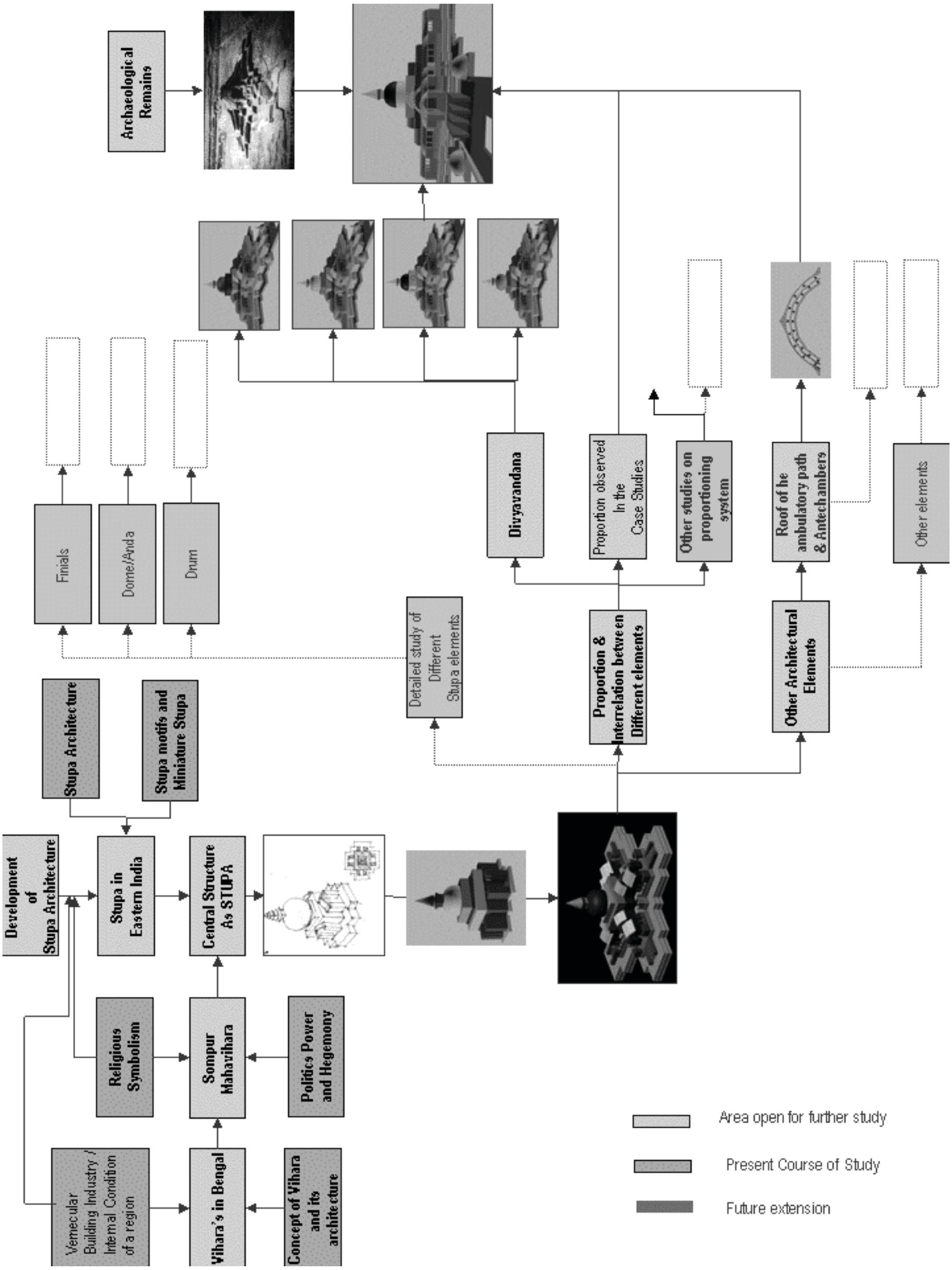


Fig. 8 Scheme showing the theoretical framework of the study with scope for future research.

Phase 2: Revisiting the Past

The question now is how the reconstruction model developed in the first phase can be used to attract feedback and interest from the wider public. This question is especially pertinent in this case as the heritage of Sompur Mahavihara is largely disregarded by the public. This is not just because the building is in ruins, but also because its context has radically changed, from a predominantly Buddhist to an Islamic environment; Muslim society simply considered it a 'pahar' or hill (which is where the name Paharpur comes from).

From this juncture emerges the concept of 'virtual heritage'. Roussou describes virtual heritage as an intersection of virtual reality and cultural heritage and states that its function is to facilitate the synthesis, conservation, reproduction, representation, digital processing and display of cultural evidences.[11] Examples of 'virtual archaeology'[12] already exist, in which archaeological sites are reconstructed for three-dimensional experiences, but it is doubtful that these successfully contribute to heritage conservation. Their end products (reconstructions of lost buildings or sites) largely remain, it seems, within academia, and only a few are published on websites or other media, or accessible to the public in museums. Virtual heritage, however, is defined more broadly: it involves not just different disciplines (architecture, computation, history, heritage, museum studies, cultural studies, etc.) but a wider spectrum of people, and will certainly benefit from a participatory approach.

The value of participation, task accomplishment and practical action for an effective embodiment with the environment is also emphasized by Dourish.[13] A successful interactive experience can only be achieved when a person is interested in the content, empathizes with it, and can imagine the alternative reality – and this can only be achieved through proper interaction.[14]

Architectural heritage can be more than the physical form. A building is a place for performing certain activities. Especially spaces inside a religious building (such as Sompur Mahavihara) are precisely guided by rituals and performances. To understand the architecture of this monument, a mere virtual reconstruction of the three-dimensional from would not suffice; it also has to embody the essence of the place. Usually in virtual environments a 'place' is a locator of objects.[15] But Kalay points out that 'places' are created through inhabitation.[16] People imbue space with social and cultural meaning, transforming mere space into a 'place'. Therefore we need to know how the design of the building is conceived through the organization of different spaces within it. As our monument belongs to the high Tantric phase of Buddhism in Bengal, its architecture was certainly determined by Tantric rituals and rites. The movements of monks within the complex, their daily life and periodic ritual performances had significant importance in the spatial organization of Sompur Mahavihara. Hence to recover the memory of this building we must examine how spaces were generated, interpreted and interconnected with respect to the daily activities and ritual performances of the monks. We have to analyse different activities and the ritual performances within the monastery and try to reconstruct the virtual model focusing on the aspects of spatiality.

A website (www.bdheritage.info) was developed in mid 2010 to present our model to the wider public and to allow for interaction and feedback (fig. 9). The model is published on the website together with earlier reconstructions by other scholars. The website also works as a virtual database where all the relevant information, research publications, images and videos are uploaded and available to the user, who can use the database for their own purposes and at the same time upload their ideas through a blog in the relevant section. Unlike most virtual heritage models, this model will incorporate also the 'intangible part of the heritage' (cultural information such as associated folk tales, local beliefs, religious beliefs, oral history, etc.). The website is continuously monitored to collate feedback and to accommodate, alter, or reject ideas for further modification of the model. Interestingly, a reasonable number of valuable feedbacks from users have been collected, and may lead to further modification of the model.

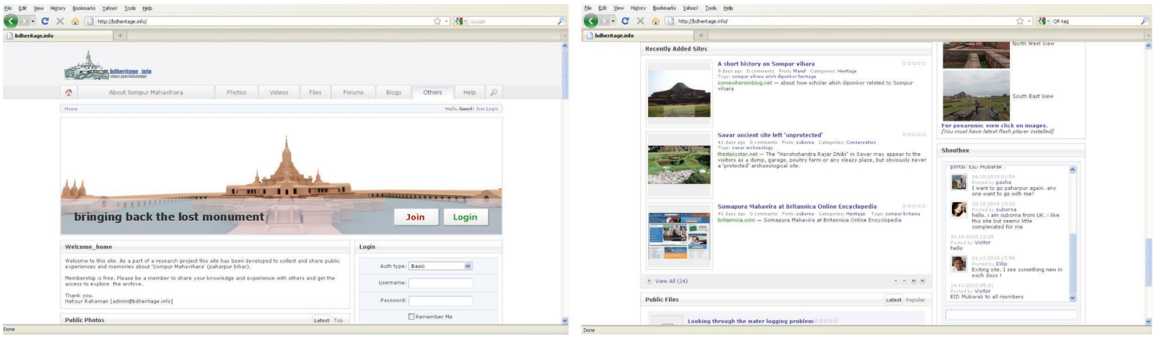


Fig. 9 Screenshots of the website www.bdheritage.info.

Another aspect currently in development is the monument's evolution through time. The history of Sompur Mahavihara is very dynamic and stretches over a period of 400 years, from the eighth to the eleventh century. The aim is to extend the virtual model to represent different phases and changes over time, what we may call 4D documentation. The website would be an excellent tool to convey such changes to the user.

The Flexible Approach – Combining the Earlier Studies

An important aspect of this study is that it continues the earlier works on Sompur Mahavihara. While criticizing earlier theoretical reconstructions it never refutes them totally, but used their contributions to develop more refined methods. Figure 10 compares the present study with the earlier reconstructions of Myer (1969) and Naqi (1999) in terms of method. Myer was more concerned with the central structure than the complex as a whole, and assumed this central structure to be a Stupa. Her approach seems to be influenced by the colonial construct of a linear progression of Buddhist architecture from South to Southeast Asia, which is probably why she identified the central structure as a Stupa that was either related with the Southeast Asian or the Nalanda type. Naqi started with studying the Vihara archetype but then focused on the central structure without motivating the connection between the Vihara and this cruciform structure. He assumed it to be a Shikhara type of Stupa, mainly basing this conjecture on the Ananda temple at Pagan and coeval Hindu temples. Naqi's assumptions were equally affected by the colonial construct of a linear development of Buddhist religious architecture through time and space.

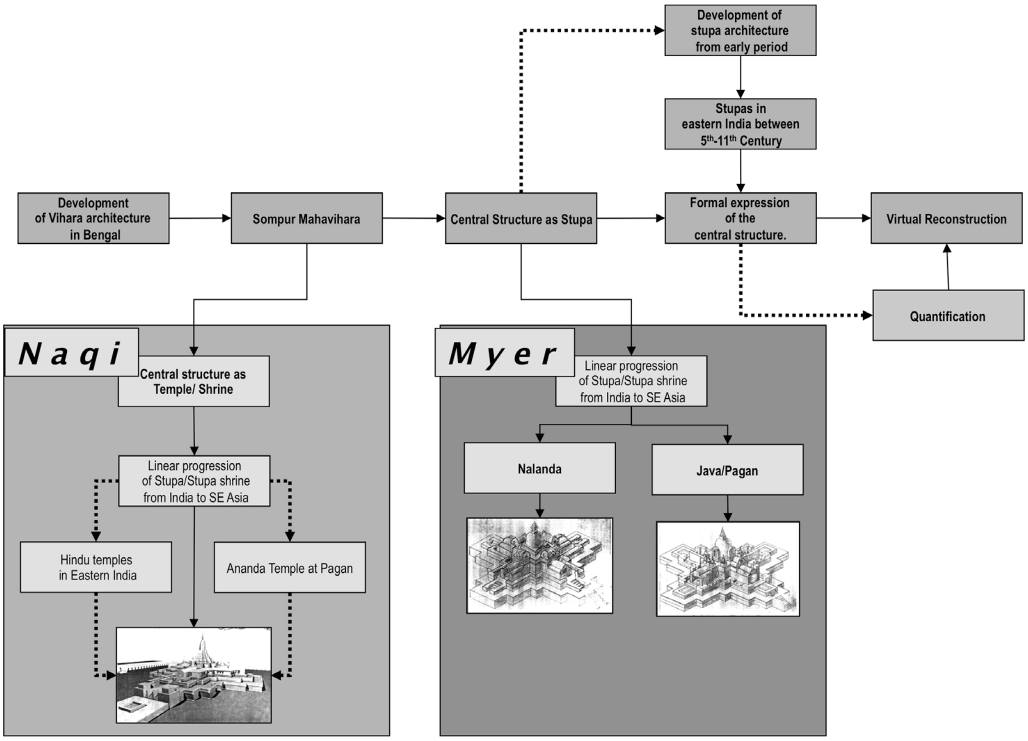


Fig. 10 Comparison of the present study with the work of Naqi and Myer.

The current study worked in two levels. The first level started from broader aspects of Vihara architecture by emphasizing regional varieties and the influence of local conditions. It tried to define the central structure with respect to the Vihara complex and to understand the preconditions that made it an integral part of monastic architecture. The second level focused on the Stupa and its architecture and was based on deductions made in the first level. At the end, the two levels were combined to create a conclusion about the form of the central structure.

These earlier reconstructions and hypotheses are all presented in the website, so that users can go through them and make their own judgement and perhaps come up with their own hypothesis by combining different findings from the different studies.

Once completed this study may demonstrate a methodology that can be adopted for other heritage sites in ruinous condition. Its main idea is to develop a process that minimizes the distance between the public and the heritage building through interaction, while at the same time conserving its memories and searching for its architectural form.

Bibliography

Barceló, J. A., 'Visualizing What Might Be. An Introduction to Virtual Reality in Archaeology', in *Virtual Reality in Archaeology*, 843 (2000), pp. 9-36.

Benisti, M., *Stylistics of Buddhist Art In India* (New Delhi, 2003).

Champion, E. and Dave, B., 'Where is This Place', in *Thresholds Between Physical and Virtual (Proceedings of ACADIA 2002)*, 2002, pp. 87-97.

Chatterjee, R., *Religion in Bengal: During the Pala and the Sena Time* (Calcutta, 1985).

Dikhshit, K.N., *Paharpur, Memoirs of Archaeological Survey of India*, Vol. 55 (Delhi, 1938).

Dutt, S., *Buddhist Monks and Monasteries in India* (London, 1962).

Forte, M. and Silliotti, A., *Virtual Archaeology* (New York, 1997).

Kalay, Y. and Marx, J., 'Architecture and the Internet: Designing Places in Cyberspace', in *Reinventing the Discourse (Proceedings of ACADIA 2001)*, 2001, pp. 230-240.

Majumder, R.C., ed., *The History of Bengal* (Dhaka, 1946).

Myer, P.R., 'Stupa and Stupa Shrines', in *Artibus Asiae*, 24 (1969), pp. 25-34.

Naqi, M.A. et al., 'The Virtual Reconstruction of Paharpur Vihara', in *Khulna University Studies*, 1 (1999) 2, pp. 188-203.

Osberg, K.M., *Constructivism in practice: the case for meaning-making in the virtual world* (University of Washington, 1997).

Rashid, M.M., 'Interpreting the Morphology of the Central Cruciform Structure of Sompur Mahavihara, Paharpur. A Cognitive Approach', in *BRAC University Journal*, 1 (2006) 3, pp. 1-8.

Rashid, M.M., 'The Conception of the Architectural Layout of Sompur Mahavihara: An Analysis of Cultural and Religious Symbolism', in *The International Journal of Bengal Art*, 9 (2006), pp. 97-110.

Rashid, M.M., 'From Stupa to Stupa Shrine. The Changing Morphology of Buddhist Religious Edifice Par Excellence', in *Protibesh/Environment: The Journal of the Department of Architecture, BUET*, 2 (2007), pp. 1-12.

Rashid, M.M., 'Defining the Central Structure of Sompur Mahavihara', in *The International Journal of Bengal Art*, 11 (2008), pp. 212-25.

Roussou, M., 'Virtual Heritage: From the Research Lab to the Broad Public', in *Virtual Archaeology*, (2002), pp. 24-25.

Roussou, M., 'The components of engagement in virtual heritage environments', in *Beyond Verisimilitude. Proceedings of New Heritage: Conference on Cultural Heritage and New Media* (Hong Kong, 2006), pp. 265-283.

Schell, J. and Shochet, J., *Designing Interesting Theme Park Rides* (2001).

Skoruupski, T. (tr.), *Kriyasamgraha. Compendium of Buddhist Rituals* (Tring, 2002).

Staley, D. J., *Computers, Visualization, and History: How New Technology will Transform our Understanding of the Past* (New York, 2002).

Illustrations

Fig. 1 Department of Archaeology, Govt. Of Bangladesh.

Fig. 2-10 Authors.

1 Chatterjee 1985.

2 There are different arguments and propositions regarding the missing part of the central cruciform structure, but in published works we came across four propositions in terms of visual representation of the superstructure. Prudence R. Myer published the first of such studies in 1969 as a journal paper, in which she proposed the missing superstructure as a stupa and illustrated its possible three-dimensional articulations. The second work was published around thirty years after Myer's proposition. In 1999 a team of architects from Khulna University led by Mohammed Ali Naqi proposed another theoretical reconstruction of the central structure and of some parts of the peripheral block (mainly the entrance hall). This work was also presented in the 'International Seminar on Elaboration of an Archaeological Research Strategy for Paharpur World Heritage Site and Its Environment' jointly organized by UNESCO and the Department of Archaeology of Bangladesh in 2004. In the same forum Mr. Shihabuddin Md Akbar, an archaeologist from the Department of Archaeology of Bangladesh, presented two possible formal expressions of the central mound. The first of these was a sketch by an anonymous Japanese architect, which he then used to develop his own version of the reconstruction.

3 Dutt 1962.

4 Majumder 1946.

5 Majumder 1946.

6 Osberg 1997.

7 Forte and Silliotti 1997.

8 A 'stupa' was originally a hemispherical mound containing the relics of Buddha and of commemorative value, but with the spread of Buddhism the form and associated meaning have changed.

9 Rashid 2008.

10 Scorrupski 2002.

11 Roussou 2002.

12 Barceló 2000.

13 Dourish 2001.

14 Schell and Shochet 2001.

15 Champion and Dave 2002.

16 Kalay and Marx 2001.

Historic Buildings through a Multimedia Experience

A Research Project on the Palaces of Sintra (Portugal)

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Maria Neto (History of Art Institute, University of Lisbon, Portugal)

Ricardo Silva (Instituto Superior Técnico, Lisbon, Portugal)

We are currently in the process of making a series of interconnected multimedia applications in order to enhance and enliven the cultural heritage of the palaces of Sintra, Portugal. These applications rely heavily on making high-quality 3D models, which focus on replicating the original buildings with precision. This process is virtually impossible to accomplish unless the model is obtained by combining a set of state-of-the-art technologies, such as laser scanning and photogrammetry. These techniques alone allow for the creation of completely reliable models of the original architectural structure. This technology permits high-resolution and accurate digital recording of the geometry, dimensions, positioning, textures and materials of the building, and allows also to map pathologies and other issues.

The project *Fala Comigo* (Talk2Me) incorporates the 3D models in multimedia applications, which also include Embodied Conversational Agents (ECAs) as a means of conveying information for educational purposes. This is an interdisciplinary project since historians generate the content while engineers and technicians design content-driven multimedia applications. From the work that is being developed, we can highlight a set of Serious Games, which also include ECAs with voice recognition and speech synthesis, along with expressive facial animations to suggest complex emotions.

Any application created for cultural heritage purposes only proves advantageous if the users interact significantly with it. The user's engagement with the created applications is established by creating the spirit and excitement of the age while the information is delivered. The 3D models play a very active role in transmitting information, mainly from their correspondence to the original buildings. The model's authenticity guarantees the user's immersion in the application, thus aiding in the learning process.

Motivation

Enjoying our country's cultural heritage is a right we all share. Hence it needs to be made available to each and everyone of us. If cultural tourism is to play a major part in the economic development of a country, it is important to plan means to sustain it. For this to happen, there must be a clear guarantee of quality, both academically and in terms of safeguarding our artistic heritage. Furthermore, the approach to numerous historical, cultural and scientific items featuring in the school curriculum can be made through works of art. Cultural heritage contains other components, a wealth of expression that must be explored from a scientific and cultural perspective.

Our two main target audiences are therefore in cultural tourism and schools. The seasonal nature of these groups can be advantageous, as the high season for the one is the low season for the other. In addition, despite their divergent needs, these two groups have many things in common, which enables heritage authorities to establish a coordinated and focused plan of action. To achieve this, there must be a commitment to producing renewed content, offering discourses aimed at different age groups and raising the awareness that preserving artistic heritage is important. These studies must be presented in accordance with modern ways of diffusion, based on emerging technologies that capture the attention of these new audiences, and establishing a framework that allows for both the dissemination and the enjoyment of heritage.

The Project

From the awareness of these needs the idea arose to produce a project combining research with proposals of implementation, with the aim of creating new products that can spread heritage information in an innovative way. Such products have already been produced in Portugal, but without an effective multidisciplinary approach. To satisfy these requirements, it was thought sensible as well as beneficial to set up a consortium based on a partnership between I&D (specialising in the History of Art and Information Technology), companies, and a body responsible for heritage management, the Parques de Sintra – Monte da Lua (PSML), which looks after the Sintra palaces.

Running for around a year now [2012], the *Fala Comigo* (Talk2Me) project aims to give users a whole new experience: attractive, simple and functional. In addition to being brought into direct contact with the monument, users are invited to immerse themselves in a virtual world, moderated by a realism that seeks to confer authenticity to the experience. While the content provided must be of the highest academic standards, the discourse must be appropriate in order to fulfil the proposed goals. Working on a project of this nature therefore implies renovation at various levels. This has to begin with an intensification of the historical and artistic research, since we need to know more about our monuments and art works to replace low-quality or even incorrect information.

The entire process stimulates creativity and implies the development of capacities. At a time when entrepreneurship and competitiveness are the order of the day, it is not hard to understand that this new approach to heritage management can be a factor in sustained development, a means of challenge and progress, which also involves considerable economic incentives. There thus needs to be a balance in the enjoyment of these direct benefits, between research and development, and between the companies, the heritage management and the general public. Fundamental to this enjoyment is the safeguarding of the cultural/artistic object. Greater accessibility should therefore be a factor in its preservation. In the discourse underlying these new 'products', there need to be warnings about the fragility of the artwork, the materials of which it is made, and the dangers it is subject to. This can subtly be presented via the historical-artistic content, but the modern heritage management programme requires that it becomes a genuine part of the visitor's awareness.

The Importance of Digitalisation

Within this campaign of disseminating and safeguarding our cultural heritage, the use of modern information and communication technology is in itself just one important preservation mechanism. Digitalisation and three-dimensional surveys are safe and reliable registers of artworks. They allow these works to be recreated virtually, so that they can be studied and even enjoyed interactively. Without even touching them, we can simulate situations and test hypotheses, for example when seeking to reconstitute parts that have been changed or lost.

The 3D survey of the monument works as an exhaustive document because it enables a complete set of architectural data to be recorded and stored. This high-resolution digital technology picks up the textural details of the materials, which makes it possible also to chart pathologies and degradation. It operates as a precise architectural information system, allowing users to explore a whole range of possible relations between the representation of the building (form, size, state of conservation, hypothetical reconstitution, record of observations over the years), as well as different kinds of information (technical, historical, artistic, and so on). It is therefore possible to create a model which provides a systematic description of multiple representations and related information, thus forming a framework for observation, analysis and multidisciplinary comparative study.

This capacity to view and review makes understanding easier as it allows working with a fixed or interactive, animated image. Underlining this ability to enhance heritage is a versatility that permits an effective dissemination through various devices, from immersive museographic tools to educational games.

These games are an important didactic means of conveying knowledge, principally for the young, who can learn by playing. Children and adolescents are the target audience for this type of product, which passes on new knowledge by linking information to the typical features of games.

A vital aspect of a Serious Game is its ability to immerse the user in a virtual world. The addition of an animated agent to the game's infrastructure allows for interaction, which greatly increases the player's experience.

The recreated monuments can perfectly operate as settings for such a game. Historical characters or ordinary, anonymous figures come to life through modern modelling and animation techniques to take part in stories or to act as knowledgeable guides to the monuments and museums or other cultural sites. These virtual agents rival reality even more closely when they are provided with an automatic voice recognition system and speech synthesis. The user can then ask these characters questions: he or she will be heard and understood, and will get an appropriate response, which is a great attraction within a conventional cultural space.

Monserrate Palace as a Case Study

Monserrate Palace, built in the nineteenth century by Francis Cook, an English merchant and great art collector, was chosen as a case study for the development of the project. The property had belonged to the Melo e Castro family but, in the mid-eighteenth century, became the residence of a series of British tenants, including Gerard Devisme, who built the first Gothic Revival palace there, and the celebrated writer William Beckford. Cook bought the estate with the ruined house and commissioned the architect James Thomas Knowles to rebuild it. Knowles carried out his commission on the former structure through an exuberant revivalist decorative programme. The various rooms were lavishly decorated and filled with sumptuous furniture, paintings, sculptures, tapestries, porcelain and crystal.

The palace and its magnificent gardens were extremely well cared for until the Cook family fortune began to fail. This led to the sale of the property in 1946 to Saúl Sáragga, with the Portuguese state showing no interest in the transaction. As a result, the interior decoration and furnishings were split up at auction. Due to the new owner's failed intention to urbanise the property, it soon fell into neglect. It was only two years later that the Portuguese state purchased Monserrate, but without any programme for the use and regeneration of the property. Occasional work on the unoccupied palace has done little to prevent its degradation. A major recuperation programme was launched in the 1990s, but it was through Parques de Sintra that the first phase of this programme was completed, which focused on restoring the roofing, floors and other infrastructures. There is currently a sectorial plan underway to restore the palace rooms, while keeping the property open to visitors and available to host events. This 'open for works' policy does not disappoint those who come to discover the palace; quite on the contrary, it has stimulated a greater flow of visitors, who can actually witness the work in progress. The policy has also meant the continuation of revenue from visitors and from hiring out the palace.

Applications

The *Fala Comigo* consortium plans to make various products using state-of-the-art technology and conceived in function of the monument's history and artistic value and in accordance with the dissemination policy of the responsible body, Parques de Sintra.

Fig. 1 The *Fala Comigo* consortium.

The palace already has a 3D survey, which was carried out by ArtScan in 2009 to support the restoration programme then underway. This was produced by using laser scanning technology, followed up by later work with various types of specific software. The laser scanner measures distances to objects, and the data coming from this tracking produces three-dimensional point clouds. Different scans along the building were carried out so as to ensure total coverage. The data produced by the survey as a whole was controlled *in situ* and in real time, allowing for immediate correction and for the gathering of additional data whenever necessary.

Producing orthophotos is a complex process deriving from the triangulation of a point cloud. Smoothing filters are applied to these triangulated surfaces, reducing their complexity. After this treatment, the geometrical surface of the object is texturised through the application of the oriented photographs.

Fig. 2 Example of an orthophoto of Monserrate Palace.

The sections and elevations are processed as a result of the three-dimensional CAD vectorisation. These files, with the respective orthophotos (on the same plane as the section or elevation) enable us to complete all the decorative features and bas-reliefs of the architectural features.

New multimedia products were conceived to explore the 3D survey of the palace. This is a precious tool in recreating a virtual reality for the monument with all the desired accuracy and authenticity. Among the products being produced, the educational game *Tesouro de Monserrate (Treasure of Monserrate)* deserves special mention, as the 3D survey plays a fundamental role in it.

Fig. 3 The game *The Treasure of Monserrate.*

Based on the story of the palace, the fictional plot centres on a group of precious artworks purchased by Cook which have disappeared without a trace. The players must find out where in the palace gardens these pieces are hidden. They subtly receive cultural information and their success depends on the amount of knowledge they learn about the monument's history. To make this possible, an immersive 3D environment was designed, based on Monserrate park. Using a topographical map of the terrain, the relief of the Sintra hills has been imported to a game engine (Unity 3D). Having acquired the natural environment, three types of setting have been created:

- An invented setting, based on some real features, but in which imagination is the major creative force.
- A setting inspired by the gardens' main features. Exact reproduction is not the aim here; only recognition of their most emblematic locations, such as Beckford's Waterfall, Vathek's Arch, or the Cromlech.
- And, finally, a real setting conferring the historical and artistic authenticity required for this type of Serious Game. What better to achieve this than the use of a 3D palace?

The 3D model of the palace had to be adjusted for use in the application, since the game's engine could not deal with the complexity of the initial AutoCAD model. This process demanded a painstaking plan of adaptation which, layer by layer, simplified each of the palace's elevations by significantly reducing the initial number of triangles.

In view of the user's virtual immersion, various other multimedia applications are being produced. Some aim to make the most recent historical and artistic research on the monument better known and exploit new documentary sources, such as the palace inventories from the time of the Cook family. The ongoing restoration process on the property has likewise been subject to greater dissemination through a multimedia system. The screening of the virtual palace is used to show how the work is progressing, exploring the visual contrast between the 'before' and 'after' stages of the campaign. The user interacts with a pedagogical agent that conveys, through simple discourse, information on the palace's history and restoration. As in the Serious Game, these applications are created in the virtual environment of the Unity 3D game engine so as to fully exploit the technological characteristics of this tool. The surrounding environment is thereby used to enhance the user's multi-sensorial experience.

Our innovative enhancement of artistic heritage also takes into consideration the kind of platforms on which multimedia applications can be installed and used. For *Fala Comigo* it was decided to focus on fixed desktop platforms as well as portable devices with the most current operating systems (Apple's iOS and Google's Android).

Fig. 4 Mobile applications.

One application allows visitors to watch the history of the palace on their mobile phones. A sequence of images from the 3D survey is included to give non-specialist visitors a better perspective of the monument's volume and space than can be achieved with plans or 2D elevations. This way, users get a remarkable autonomy and can therefore orient their visit as they please, though always supported by concise, accurate and clear information. Once acquired, the informative digital content belongs to the user, who can store it in his mobile phone for later use, for example to create a digital reference library of places visited.

Future Work

The main aim of the final phase of project development is to explore the 3D model of the palace's interior, so as to map out the course of a virtual visit. This will make it possible to recreate, in detail, the atmosphere of the period by means of furniture and other decorative features. The possibility of offering visitors a faithful reconstruction of the palace in its golden age will certainly contribute to renewing interest in the monument. By virtually exploring rooms that are actually empty at present, visitors will get a genuine feel of how life was lived in these interiors at the time of the Cooks.

The success of this group of applications will decide the fate of similar applications that are conceived for other palaces in Sintra under the management of PSML.

Conclusion

3D surveys of buildings are today recognised as important information systems in various fields. For a historic monument it is also an essential aspect of its safeguarding. Its use, however, is not limited to these important areas. Because a 3D survey can play a suggestive role in reproducing, recreating or simulating reality, it can be used in multimedia applications for the dissemination of knowledge of our cultural heritage. The immersive power of the 3D image pulls users into a world, which might be parallel to the real world, that stimulates our senses to be fully active. It is now within our reach to create an educational game which recreates a time and a space, passes on cultural content, reconstructs the life and times of a particular monument, and makes it possible to travel in time and virtually visit that monument. We hope that this new initiative in the world of emerging technology will generate widespread and sustained benefits for artistic heritage and may thus contribute to its preservation.

Bibliography

De Troyer, Veerle, ed., *Heritage in the classroom. A practical manual for teachers* (Antwerp, 2005).

ERCIM News (European Research Consortium for Informatics and Mathematics, Special Theme: *ICT for Cultural Heritage)*, no. 86, July 2011.

Zyda, Michael, 'From visual simulation to virtual reality to games', in *IEEE Computer*, 38 (2005) 9, pp. 25-32.

Neto, João N., Silva, Ricardo, Neto, João P., Madeiras Pereira, João and Fernandes, João, 'Solis Curse – A Cultural Heritage Game Using Voice Interaction with a Virtual Agent', in *Third International Conference on Games and Virtual Worlds for Serious Applications* (2011), pp. 164-167.

Neto, Maria João, 'Coleccionadores e connaisseurs de obras de arte: Francis Cook (1817-1901) e John Charles Robinson (1824-1913) em Portugal', in *Artis, Revista do Instituto de História da Arte da Faculdade de Letras de Lisboa*, 6 (2007), pp. 403-442.

Ilustrations

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Fig. 3 ArtScan.

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This volume explores the potential role of virtual models for scientific research on historic palaces. The rise of digital surveying and modelling techniques has revolutionized the ways in which historic buildings such as court residences can be studied. These new techniques offer unprecedented opportunities for architectural historians but also lead to new challenges.

One challenge is the reliability and verifiability of the data that is used to make digital models, whether surveys of extant buildings or reconstructions of lost buildings. Another is the use of virtual palaces as research instruments in their own right – not just to communicate results to the wider public, but as genuine research tools that help visualize and clarify hypotheses about issues such as construction phases or the spaces' ceremonial use.

The five papers collected in this volume offer multidisciplinary case studies that focus on the surveying, recording, digitizing and modelling of extant palaces in their present state. They also look at the possible uses of the resulting digital models as instruments for further research and as vehicles for the preservation and propagation of knowledge.

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