VISUALISATION
OF CULTURAL HERITAGE OBJECTS
AND ITS DISSEMINATION

COSCH WORKING GROUP 5
REPORT ON ACTIVITIES 2012–14

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ABSTRACT: This interim report covers the activities of the Working Group 5 (WG5) of "Colour and Space in Cultural Heritage" (www.cosch.info), the COST Transdomain Action TD1201, supported by the European Cooperation in Science and Technology between 2012– 2016. The report covers the period from 2012 to 2014. Three-dimensional visualisation is a result of complex interactions between researchers and editors, science and technology specialists, with resources, the project background and contexts, and diverse working processes. Among the important issues that arise in this field are the high cost and access to the technical expertise and instruments needed to incorporate this technology in traditional Cultural Heritage (CH) research, the lack of automation and consistent standards, the huge amount of data produced, their variety (3D models, geographical data, metadata, paradata etc.), as well as their efficient and effective management, especially in terms of sustainability and long-term archiving. These restrictions are particularly acute within museums and other CH institutions, while the lack of appropriate principles and methods of documentation neither assures quality in relation to a scholarly content, nor use of knowledge contained in these 3D models for future generations.
The purpose of this report is to identify similarities and differences of typical working processes and methodologies in the field of 3D modelling of material cultural heritage. Based on research conducted by the COSCH participants, general phases of a visualisation process, methodological strategies, as well as a CH visualisation typology are defined. The report offers recommendations for further work within the COSCH network and development of guidelines for scientific and CH researchers, and general public, that will assist them in 3D visualisation of cultural heritage.

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1. INTRODUCTION

Selma Rizvić

Three-dimensional (3D) computer models make it possible to present a great deal of information about cultural heritage (CH) at a glance. They are not only useful for presenting research results in a way that appeals to a larger public; they are also an extremely helpful research tool.

Thus, on the one hand, computer models of CH assets, when published or displayed in exhibitions, help the general public see representations and reconstructions of historic objects and structures, often in their environment, and appreciate how they evolved through time. On the other hand, they allow the scholarly testing of different hypotheses, and often enable the clarification of questions that are difficult to investigate on a theoretical level only. Flexible and transparent 3D models help to illustrate all ideas and information that lead to more than one possible historical reconstruction, which arise from the gathered evidence.

Despite the growing importance of 3D visualisation of cultural heritage, there are no binding standards or guidelines in relation to working processes, terms or documentation of knowledge. The London Charter for the Computer-based Visualisation of Cultural Heritage [Denard, 2009] has stimulated a relevant discussion, but its principles are only general. The 3D visualisation of CH has not yet become the focus of a relevant comprehensive document that would effectively cover the growing number of possible applications and techniques. This results in several problems for the use of 3D models in CH research in terms of knowledge evidence, sustainability and long-term archiving of research outputs.

The scope of integrating these modern 3D technologies in the traditional heritage research is broadly to record and better manage the material CH assets; to put the latter into a bigger picture and support their interpretation; to visualise and reconstruct the CH data; to assist in the preservation and dissemination of CH assets; and last, but not least, to enhance the "edutainment" value of virtual CH by widening the appeal of scholarly visualisation to the general public.

Three-dimensional visualisation is a result of a complex interaction of resources, project background and contexts, researchers and editors, science and technology specialists, and diverse working processes. Among the important issues that arise in the field are the high cost and access to the technical expertise and instruments needed to incorporate this technology in traditional CH research; the lack of automation or standards, the huge amount of data produced, their variety (3D models, geographical data, metadata, paradata etc.) and of course

their efficient and effective management, especially in terms of sustainability and long-term archiving. These restrictions are particularly acute within museums and other CH institutions, while the lack of appropriate principles and methods of documentation neither assures quality in relation to a scholarly content, nor use of knowledge contained in these 3D models for future generations.

The purpose of this report is to identify similarities and differences of typical working processes and methodologies in the field of 3D modelling of CH. Based on this, a further purpose is to define general phases of a process and strategies in the methodology, as well as a definition of CH visualisation typology.

Cultural heritage is often visualised for purpose of presentation of objects which do not exist anymore or only their remains have survived on archaeological sites or in museums. Apart from the scholarly use of 3D models, such applications are successfully targeting the general public. The tendency is to differentiate between requirements of a 3D model, depending on the user groups. In any case it is essential that the users evaluate their quality. Therefore in this report some observations on both, the scholarly and casual use, are presented, and include an example of qualitative user evaluation, as an effective methodology for the user experience theory.

The report concludes with recommendations for further work by COSCH and development of guidelines for scholarly and scientific researchers, and the general public alike.

2. STATE OF THE ART

2.1. 3D Visualisation in Archaeology

Despoina Tsiafakis

Digital archaeology has evolved for many decades now, to become a "scientific discipline that seeks to research and develop ways of using computer-based visualisation for the comprehensive management of archaeological heritage" (López-Menchero Bendicho, 2013: 282). More specifically, in archaeology, 3D visualisation is a scholarly field that includes the use of modern 3D computer technologies in the comprehensive management of archaeological heritage. These technologies support the excavations, and may also be applied to the excavation finds, both movable and immovable.

The following case studies are indicative of the applications of 3D technologies in both excavations and the management of excavation finds.

A very useful and systematic example of modern application of such technologies is the excavation in Boudelo-2 in Flanders, Belgium (Figure. 2.1), in which the excavation was recorded in 3D, making the entire process

faster and more efficient than with more traditional methods (De Reu et al., 2014). The excavation explored part of a reclaimed medieval wetland, which was part of the monastic outer court of the former Cistercian abbey of Boudelo. Due to the variability in archaeological features and the soil characteristics, the Boudelo-2 excavation offered ideal opportunities to test the 3D-recording workflow.
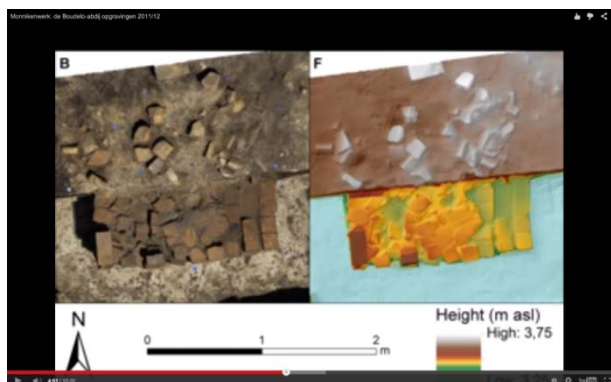

Figure 2.1. Screenshot from the promotional video of the image-based 3D documentation of the Boudelo excavations http://youtube/2rncVW3mkhE

A similar project, 3D-Digging at Çatalhöyük, a Neolithic site in Turkey (www.catalhoyuk.com/uc_merced.html, see Figure 2.2), aimed to virtually reproduce the entire archaeological excavation both on site, during the dig, using different 3D technologies, and in the lab, through tele-immersion, by using 3D Virtual Reality (Forte et al., 2012).
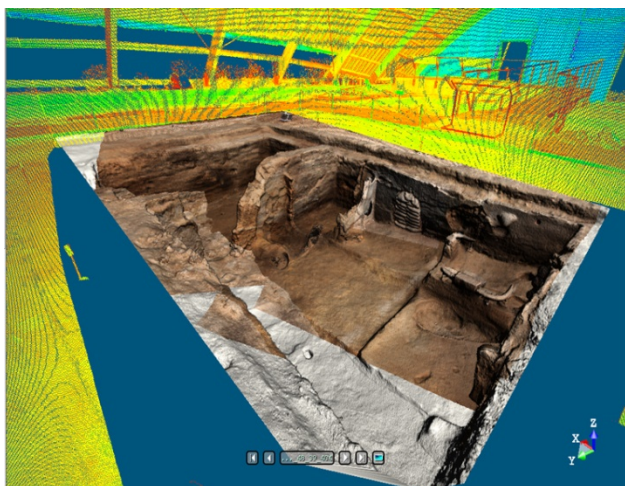

Figure 2.2. Image of the excavation 3D model http://www.catalhoyuk.com/images/merced/image005.jpg

From the outset, the project has identified archaeological questions that 3D technologies could support, focusing especially on the enhancement of interpretation through technological tools (Forte et al., 2015). Moreover, the project team tested different protocols and technologies

in order to achieve full standardisation of different categories of data for different software platforms (Forte et al., 2015). A robust methodological workflow was adopted that allowed a quick and functional integration of 3D data recording, handling and interpretation in the course of conventional, daily fieldwork and throughout a study process. Thus, it worked with a 3D system considered reliable for archaeological documentation, with sufficient accuracy, reasonable time frames and budget. Indeed, through the manipulation of 3D data the project team acquired new information that would otherwise have remained hidden and achieved outstanding results (Forte et al., 2015).

In the excavation of the Can Sadurní cave in Begues, Barcelona (Figure 2.3) the finds (objects, layers etc.) were located in the complete model of the cave and a GIS was implemented to achieve a more complete and complex analysis of the artefacts (Núñez et al., 2013). There, four human skeletons were discovered from the beginning of Middle Neolithic (about 6,400 years ago). They were buried following an unknown ritual in the Iberian Peninsula (www.ub.edu/web/ub/en/menu_eines/noticies/2013/11/04 4.html). The system used provided both the spatial context in which objects were found, i.e. the archaeological stratigraphy and its sedimentation process, and the texture and colour information related to the different objects. The data produced were efficiently managed thanks to a database linked to geographical objects.
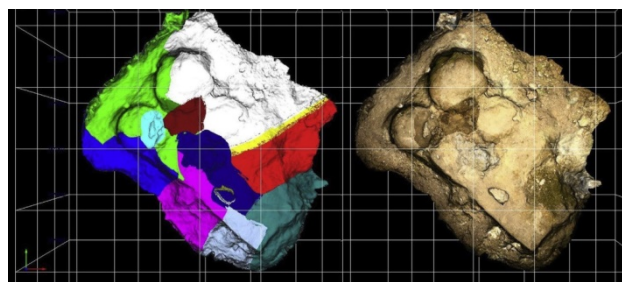
Figure 2.3. Isometric view and model with contour lines of a combustion structure in Can Sadurní cave (Núñez et al., 2013: 4425)

The reconstruction of an ancient Greek ceramic vessel, a fruit stand *karpodoche* (Figure 4) has been repeatedly used in archaeological studies (Tsiafakis et al., 2006; Tsiafaki, 2012). This 3D reconstruction of pottery from the Karabournaki site was created and stored within a digital database of the entire excavation, along with relevant photographs, drawings, profiles and trenches, making the study of a particular shred as versatile as possible. 3D printing enables reproduction (actual size or to scale) and manipulation of models (Forte et al., 2015). This becomes extremely useful for long-distance measurements and views on a remote workstation (De Reu et al., 2014).

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Figure 2.4. Image illustrating the process of 3D reconstruction of a *karpodoche* from Karabournaki (Tsiafaki, 2012: 159).

Although simplified, the Virtual Hampson Museum (http://hampson.cast.uark.edu/) is similar. It showcases a series of 3D digital artefacts from the collections of the Hampson archaeological Museum State Park. In the virtual museum, visitors can browse the 3D collection, download data, read descriptions of each artefact and interact with them. 3D visualisations of the sites from where the artefacts come are also provided to the visitor. Such and similar efforts to create virtual archaeological exhibitions can be used for both promotional purposes and cultural or educative aims (Bruno et al., 2010).

Figure 2.5. 3D computer model of a headpot from the Virtual Hampson Museum
http://hampson.cast.uark.edu/artifact.php?IDart=1

In Karabournaki (http://karabournaki.ipet.gr/, Figure 2.6) 3D technologies are used, through the collaboration with the "Athena" Research Centre, for the recording and reconstruction of certain portable finds and the registration of the dig layers with 3D GIS (Tsiafakis et al., 2004; Tsiafakis & Evangelidis, 2006; Tsionas et al., 2009). Useful comparisons between various processes (in terms of cost, time, geometric and reflectance quality) are performed in Pompeii, providing an adequate assessment

of the pipeline (Apollonio et al., 2012; Dell' Unto et al., 2015).
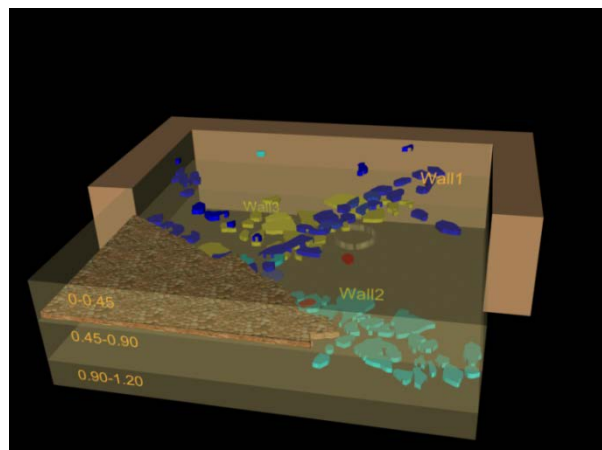
Figure 2.6. 3D GIS recording of the Karabournaki site

Technological tools can enrich and extend an archaeological survey. The 3D digitisation project, 3DICONS (Tsaouselis, 2015) is a good example. It was conducted with the aim to provide *Europeana*, an online collection of cultural heritage resources in Europe, with 3D content. The resulting computer models of monuments of world heritage significance, include the model of the church of the Holy Apostles in Thessaloniki, Greece (Figure 2.7). Through the manipulation of a detailed 3D model of the church an unpublished inscription was revealed, located on a drain pipe (Koutsoudis et al., 2014). The finding of such an inscription on the roof of the church would otherwise be much more difficult.
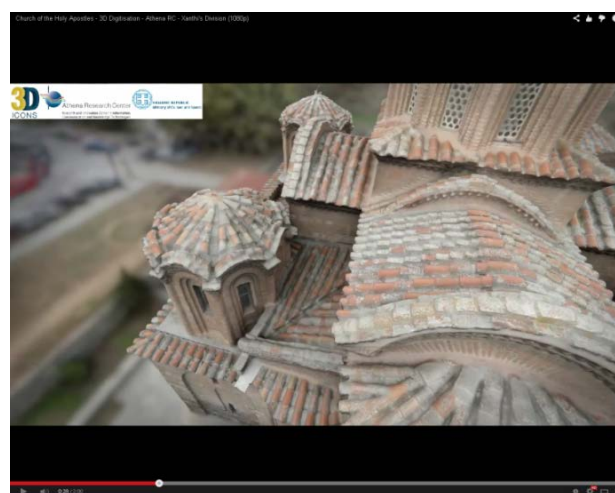
Figure 2.7. Screenshot from the animation of the 3D digital replica of the Church of the Holy Apostles
http://youtu.be/SvASaCuhaNI

2.2. INTERACTIVE VISUALISATIONS

Selma Rizvić

Interactive visualisations of cultural heritage have been implemented in the last few decades through many projects and case studies. They range from 3D scanning and virtual restoration of damaged artworks and artefacts to interactive virtual reconstructions on various scales, from single monuments to entire cities.

The pioneering Digital Michelangelo project (Levoy, 2000) developed a hardware and software system for digitising the shape and colour of large, fragile objects under non-laboratory conditions, using laser triangulation rangefinders, laser time-of-flight rangefinders, digital still cameras, and a suite of software for acquiring, aligning, merging and viewing scanned data. As a demonstration of this system, ten statues by Michelangelo were digitised, including the well-known figure of David, two building interiors, and all 1163 extant fragments of the Forma Urbis Romae, an enormous marble map of ancient Rome. It was one of the earliest achievements in cultural heritage digitisation, introducing the issues of large data sets and their management in research. Some of those issues were addressed and solved through MeshLab, a system for the processing and editing unstructured 3D triangular meshes (Cignoni et. al, 2008).

Ancient history comes to life through virtual walks around the Ancient Olympia (Gaitatzes et. al, 2005) and the Valley of Pyramids in Giza (Der Manuelian, 2013). The Virtual Reality programme at the Hellenic Cosmos Theatre in Athens includes a tour of the peninsula and the city of Miletus, as it might have been 2,000 years ago. Visitors can explore the virtual city and learn about the most important public buildings. Starting at the gate of the Port of the Lions, they 'enter' the sanctuary of Apollo Delphinios. Then, they 'visit' the Ionian Stoa, which housed the stores of the city, the Hellenistic Gymnasium, the North Agora and the Bouleuterion. They are able to see this architecture in great detail. They may 'fly' over the city and enjoy a panoramic view of the perfect urban design, or even 'dive' into the port.

Of note is the Giza Project conducted at the University of Harvard. It is concerned with the famous Pyramids of Giza, the Sphinx, and surrounding tombs and temples from the third millennium BC, just west of modern Cairo. Archival material in various formats (including digital photos, archaeological drawings, object metadata) are being combined with realistic 3D visualisation of the site. This project provides novel access to Giza, its statues, hieroglyphic inscriptions, architecture, and wall decoration. Real-time immersive models allow the visitors to pose new research questions; provide interactive classroom instructions; and investigate diachronic approaches to Giza's evolution over several millennia.

The advantages of 3D technologies have also been proven in protection of cultural heritage sites through prevention of damage caused by excessive numbers of visitors. New forms of visitor engagement emerge. The Pure Land project, for example, involved 'a full-scale augmented digital facsimile of Cave 220, in the Mogao Grottoes, Gansu Province, north-western China'. The site is listed as a UNESCO World Heritage site. The priceless paintings and sculptures at Dunhuang are extremely vulnerable. 'Comprehensive digitisation has become a primary method of preservation at the site.' (Kenderdine, 2013)

The Virtual Museum Transnational Network (V-MusT.net) has integrated a number of interactive visualisations of cultural heritage into the international multimedia exhibition, *Keys to Rome* (Keys to Rome, 2014). The exhibition was held at the same time in Rome, Amsterdam, Alexandria and Sarajevo. These four locations were presented at the time of the Roman Empire through an interactive storytelling application enabling the visitors to walk through Roman villas and thermal baths, basilicas and temples, collecting objects and learning about their history.

The mentioned projects represent just a small fraction of virtual cultural heritage applications. Through this work some open issues aroused and have been identified by Scopigno (Scopigno, 2013). Some of the problems are still subjects of intensive scientific research: achieving interactivity without compromising on the quality (simplification and multi-resolution); web and mobile presentations of the interactive virtual environments; finding the best interaction and navigation methods; and integration with other media.

2.2.1. Interactive Digital Storytelling Applications for Cultural Heritage Visualisation

Since the beginning of mankind people have communicated through telling stories. Throughout history the concept has remained the same, but the tools and methods have changed with time. People started writing down their stories, recording at first the sound of their voices and finally recording audio-video clips, nowadays called movies. Digital technologies enhanced the ways of presenting stories and digital storytelling was born.

"Digital storytelling is narrative entertainment that reaches the audience via digital technology and media." Miller argues that digital storytelling techniques can make a dry or difficult subject more alive and engaging to the viewers (Miller, 2008).

In order to improve the classical storytelling concept further, Glassner defined interactive storytelling as a two-way experience (Glassner, 2004), where 'the audience member actually affects the story itself'. Manovich also introduces the possibility, for an audience, to change the

story. He proposes the concept of an interactive narrative as 'a sum of multiple trajectories through a database' (Manovich, 2002).

A Human Sanctuary is a project implemented by the Cyprus Institute. It tells the story about the famous Dead Sea Scrolls. Text annotations offer more details about certain notions mentioned in the video (Human Sanctuary, 2013). In the *Keys to Rome* exhibition (Rizvic et. al, 2014) the interactive digital storytelling was used to present the reconstructed Roman remains from Rome, Amsterdam, Alexandria and Sarajevo in combination with physical museum exhibits.

Interactive digital storytelling is the main methodology employed in most projects of Sarajevo Graphics Group. It has been implemented in virtual reconstructions of cultural heritage objects, which do not exist anymore, or only their remains are present, and in virtual museum applications. This research started with an interactive video virtual tours (Kraljic, 2008), where the user watches video walks through the streets of Sarajevo old town, navigating through 'decision points'. It was the concept of 'a story-guided virtual museum', implemented in the Sarajevo Survival Tools project (Rizvic et al., 2012). The digital story provides the user with the historic context of the siege of Sarajevo, 1992–1996, guiding him or her through the virtual museum of objects created by the citizens during that time. The virtual exhibition is divided into thematic clusters. The stories connect these clusters. Sljivo (2012) introduced the concept of audio-guided virtual museum and evaluated it through user studies. Audio stories were implemented to guide the visitor through the virtual collection of Bosniak Institute exhibits. The user evaluation showed that visitors were so focused on the story that they did not notice that movement through 3D environment was not enabled. They could move only by clicking hotspots in the pre-rendered images. In the computer animation of the *zikr* ritual in Isa bey's tekke (Huseinovic, Turcinhodzic, 2013), the animated virtual environment was exported to Unity 3D and adjusted to place the user in the middle of the animation. The user may observe this Dervish ritual going on around him or her, and has a possibility to explore the highlighted elements in more detail. The main story happens in the ritual room, *semahana.* The sub-stories are connected to elements of the scene that are highlighted and activated on a mouse click. After the activation every sub-story is implemented as a movie.

The next improvement of these interactive storytelling concepts was implemented in the Isa bey's endowment project. It united the interior animation of the *zikr* ritual with the exterior virtual environment consisting of the *tekke*, the accommodation complex, soup kitchen and water mills. The main story about the endowment, and sub-stories about particular objects, are realised in form of audio-stories in corresponding areas (Rizvic, Sadzak et.

al, 2014). The main story starts once the user activates the interactive environment. If the user is detected inside one of these activation areas, a trigger is launched to pause the main story and start the sub-story corresponding to the activated area.

The concept developed most recently is based on interconnecting the video file of the main story with sub-stories and the interactive 3D model of the Tašlihan object, using the Unity hyperlinks. In this application (Taslihan, 2015), the main story represents a summary of the information about the object, its history and related events and characters. It consists of seven thematic clusters (MS 1-7). After each thematic cluster the user can activate a link to the sub-story (SS), which describes in more detail a topic mentioned in the main story. Rizvic et al. (2015) showed that the storytelling is much more engaging and immersive if there is a character telling the story. Therefore in this project the story is told by Murat Bey, the first associate of Gazi Husref bey, who sponsored the construction of Tašlihan, the largest accommodation complex in Bosnian province of the Ottoman Empire.

3. ANALYSIS OF TYPICAL APPLICATIONS OF VISUALISATION TO CULTURAL HERITAGE

3.1. Analysis of 3D Visualisation in Archaeology

Despoina Tsiafakis

One could say that archaeology is about the past and the contemporary use and understanding of old things. Archaeologists, when they dig, study, interpret and present the various aspects of past human activities, are limited by various factors. Among these factors are the destructive nature of excavating itself and the fragmentation of archaeological remains. They may not be able to see the bigger picture of a culture in which an excavated site is situated. The typological classification of the finds may be very difficult. All these factors narrow the possibilities of recording, analysing and publishing the findings, about a site or a monument, easily and quickly.

Information and communication technologies, especially 3D applications, can give a new boost to both excavation and later study. The advantages of applying some of these technologies outweigh possible difficulties encountered along the way (De Reu et al., 2014). Especially, the enhancement of interpretation, by both experts and non-experts, is unquestionable. A 3D model can make a cultural asset 'speak', thus becoming a visual guide for archaeologists and the general public. It is a way of representing the past more vividly than through an architectural drawing or 2D photograph. Moreover, it has the significant ability to provide a new way to engage mass audiences with the physicality and materiality of objects; it helps showing the connection between the

active excavations and archaeological sites on the one hand, with museum collections on the other.

The aim of integrating modern 3D technologies in the traditional archaeological research is mainly a) to record and reconstruct the excavation procedure, which is highly destructive; b) to visualise, contextualise and better manage the excavation data; c) to limit the common 'fragmentation' of archaeological remains; d) to support the classification and typology of archaeological finds, especially pottery; and finally e) to support archaeological research community in education, or edutainment, of the general public.

The relevant applications can range from 3D GIS to image-based or range-based recording, photogrammetry and virtual 3D modelling. A variety of hardware (less or more complex) and software (commercial or open-source) may be used, widely ranging in cost. The resulting 3D digital model may be produced in various formats and sizes, in order to be used for many purposes and on different digital platforms by experts, non-experts and general public respectively.

Digital 3D recording is a primary application of Information Technology to archaeology and cultural heritage. The aggregation and presentation of the assets of European culture was an aim of EUROPEANA (http://www.europeana.eu), supported by the European Union. Good practices and standards in archaeological documentation (CIDOC-CRM, Dublin Core, etc.) have been adopted in order to ensure the interoperability of the digital cultural content assembled in this vast digital repository. To empower the adoption and extension of standards, networks of experts have been created to foster an interdisciplinary approach.

The use of 3D cultural content has dramatically increased over the last decade. A number of research and development projects [CARARE, 3D-ICONS, 3D-COFORM], and other initiatives, have focused on establishing 3D documentation as an affordable, practical and effective mechanism that allows the content of cultural heritage digital libraries to be enriched with 3D digital replicas. Three-dimensional digitisation is considered a common practice in the cultural heritage domain.

Several experimental software tools and methodologies attempt to enhance archaeological research with 3D technologies. Studies of pottery may be organised according the use data derived from 2D profile images, complete or incomplete 3D vessel replicas and 3D shreds, including the problem of reassembling pot fragments. In general, the description of shape and shape matching of 3D cultural objects are two interlinked problems from which many research domains may benefit.

Dissemination of cultural heritage is amongst the main objectives of 3D digitisation. Numerous 3D models of the treasures have been published on the Internet. Three-dimensional computer models contribute to the reconstruction of the past. The 3D models of monuments or of archaeological sites, or even urban areas, can be aggregated into collections of multiple 3D objects. It has already been discussed by researchers that annotating interesting parts of a 3D scene with metadata that describe thematic aspects and properties of the included entities (e.g. artefacts, statues, buildings, etc.) can be of great importance.

3.2. Graphical Documentation Applied to the Analysis, Conservation and Dissemination of Historic Buildings. State of the art

Rafael Martín Talaverano
José Ignacio Murillo Fragero

The graphical documentation of historic buildings has two main objectives that should always be considered. First, it provides the safeguard of the cultural values of the building through a rigorous documentation of the several elements that configure the whole construction. Second, the graphical documentation is the main tool for the development of analyses, conservation and dissemination campaigns for historic buildings. Depending on the objective, the requirements for the graphical documentation can be deducted in each particular case, taking into consideration the specific features of the building and future needs. These aspects should determine the choice of a specific technique for carrying out the graphical documentation of a building.

3.2.1. Techniques of Graphical Documentation of Historic Buildings

Currently, there are many techniques for graphical documentation of buildings. They can be divided into the following main groups:

- Manual survey. It relies on the manual acquisition of data. Several kinds of devices are available, such as a tape measure, plumb bob, tachymeter, spirit level and laser distance meter. They provide direct and quick data that can be captured in almost any condition of light and space. However, such data are not related to a common reference basis and since they are not digital, they must be hand recorded in drawings. They are therefore mainly used for complementary data acquisition of one of the following techniques:

- Instrumental survey. This technique relies on the devices for measuring a set of points in a building. Digital data (x, y, z coordinates) all relate to a common reference system. There are many kinds of devices, including basic total stations, image stations or laser scanner. The main differences are the automation level of the data

acquisition. Total stations measure single points, so that the user has to select them beforehand. It takes a long time and a previous analysis of the building is required, but the resulting data are already 'effective' data. On the contrary, a laser scanner is a fully automated device that measures a large number of points indiscriminately, without any previous selection. That allows obtaining a great number of data (a dense point cloud) in a relatively short time. However, much of them are useless, so that the user must develop a sometimes hard filtering process. Some devices, such as image stations and laser scanners, incorporate photo cameras which allow obtaining colour and texture information for each point measured. Point clouds can be first converted into triangle meshes and, second, the colour of each triangle can be calculated. A 3D realistic textured model is achieved. It may be projected on a specific plane to obtain a true scale orthoimage.

- Digital photogrammetry. This third main technique consists not on measuring points in the building directly, but to calculate them from one or several images taken with photo cameras. The main advantages are the low cost, as well as the relatively short execution time on site. Several groups of sub-techniques can be noted. The simplest way is the rectification of a plane element from a single image; it could be defined as '2D photogrammetry'. It is a fast and economical technique that has the only restriction of limited use for plane elements. However, with a topographical support it can be used in a great number of cases, resulting in 2D drawings over the rectified images. Three-dimensional photogrammetry also provides 3D models and spatial digital data, and can be subdivided in two main groups. The method based on sets of two images with parallel directions and only separated by a certain distance between them (the so-called stereoscopic photographical pair) gives the opportunity to virtually watch the three dimensions of the building in a digital stereo rectifier and to spatially draw over it. The result is a complete 3D model based on the drawn lines, so that the elements of the building are already defined.

The so-called multi image photogrammetry is an alternative method. It uses a set of several images from different points of view. It provides a dense point cloud similar to that acquired by a laser scanner, so that a 3D mesh, a 3D realistic textured model and a true scale orthoimage can also be acquired. In all cases, a topographical support is required for the developing of a complete 3D model of a building.

3.2.2. Conceptual Basis for Graphical Documentation of Historic Buildings

The evolution of the techniques in question has been considerable in recent years. Methods and applications are being updated on a daily basis. The possibility of achieving 3D models and true-scale orthoimages through laser scanning or digital photogrammetry has expanded beyond the limits of traditional graphical documentation. New developments in the audio-visual fields, in virtual and augmented realities, holographic reconstructions, mapping, etc. are emerging.

However, the main objectives and principles of graphical documentation must not be forgotten under any circumstances. A rigorous record of the cultural values of the building is the key for its safeguarding. It is also the essence of the graphical documentation as a fundamental tool for other activities; this implies the compatibility and feasibility of use by several users. These conditions have traditionally been solved by the 2D architectural drawing (elevations, plans and sections), whose understanding was common between professionals.

Some researchers believe that 3D models produced through laser scanning or digital photogrammetry will substitute architectural drawings. In our opinion, for two reasons this is completely wrong. First, the representation of buildings is a subjective interpretation of the built reality based on a deep knowledge of their construction. A thorough analysis is required to arrive at this good understanding. The sequence of analysis, interpretation and representation may only be fully developed through the drawing process, but not through highly automated processes of producing 3D models using laser scanning or digital photogrammetry. Second, architectural drawings are the sole most efficient tool, employing a universal language that is independent of specific technological devices. That is why 2D architectural drawings should always be included in the graphical documentation of historic buildings, although 3D models are undoubtedly very powerful tools to obtain and complement the drawings.

3.3. Evaluation of Selected Projects Carried out at the Faculty of Electrical Engineering, University of Sarajevo and King's College London, UK

Mieke Pfarr-Harfst

3.3.1. Approaches

In the course of a COSCH Short-term Scientific Mission (STSM), selected projects involving applications of historical visualisation, carried out at the Faculty of Electrical Engineering of the University of Sarajevo and King's College London, respectively, were analysed and evaluated. Various factors influencing the process of 3D modelling were part of the investigation. Before the survey

was started, the factors were defined as a basis for the systematic and objective investigation of the projects.

The projects to be investigated at the institutions in question were selected with the view of a wide-ranging diversity of objectives, results, partners, techniques and methods, to encompass the broad scope of applications of visualisation and 3D models in the cultural heritage domains.

3.3.2. Methods

Projects investigated in London

At King's College London the following projects of King's Visualisation Lab were investigated:

- Body and Mask in Ancient Theatre Space
- Oplontis Visualisation Project
- The Skenographia Project
- Roman Coins

Projects investigated in Sarajevo

At the Faculty of Electrical Engineering of the University of Sarajevo:

- Stecak
- Virtual presentation of Sarajevo City Hall
- Information Perception in Virtual Heritage Storytelling Using Animated and Real Avatars
- Virtual Sarajevo – Baščaršija project
- Virtual National Museum of Bosnia and Herzegovina
- Isa-begova tekija project
- The Church of the Holy Trinity in Mostar
- Bosnian Traditional Objects
- Interactive digital catalogue of Stecaks
- Multimedia presentation of Saborna Church in Sarajevo
- Virtual Museum of Sarajevo Assassination
- Sarajevo Survival Tools
- Sarajevo Time Machine
- Isa bey's endowment
- Keys2Rome exhibition

These projects can be accessed through the Sarajevo Graphics Group website.

3.3.3. Parameters

The investigation of these projects was conducted based on the defined, objective factors called here parameters:
- Background of the project
- Context of the project
- Schedule
- People involved
- Objectives and aims of the project (research, transfer of knowledge, preservation)
- Application field
- Application/ preservation format
- Possible areas of application
- Type of 3D visualisation method

- Technical system/aspects
- Methodology and steps in the working process
- Results
- Type of cultural heritage

These parameters have been defined in the course of earlier research (Pfarr-Harfst, 2013) and (Munster, 2011). The identification of common parameters is necessary for an objective investigation and the comparability of the results. Furthermore, this investigation may support other research questions addressed through the COSCH Action, COSCH[KR] and future research projects. All these parameters of visualisations and 3D models of cultural heritage are closely connected to each other.

3.3.4 Resources

The documentation of each of the previously mentioned projects in the form of virtual presentations provided by the institutions involved, as well as the results of the different meetings and discussions, supported the investigation.

All information available about the projects was organised according to the identified parameters. A survey map of each project resulted from this first step in the investigation and was a basis for evaluation. The working process of each project was visualised in a diagram.

3.3.5. Main Findings

The results of this investigation fall into two main topics:
1. Definition of types of CH visualisation
2. Definition of a process as an input-output schema

3.3.5.1. Definition of Different Types of Cultural Heritage Visualisation

Based on the investigation of selected projects, eight types of CH visualisation have been defined (Figure 3.1):
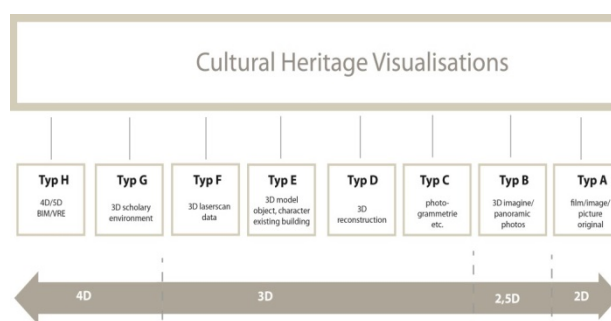

Figure 3.1: Diagram showing types of CH visualisation. *See COSCH WG5 Interim Report Appendix for a larger version of this diagram.*

Type A: Images, renderings or films resulting from a 3D dataset or from image-based 3D modelling; original raw, unedited film footage or image as a Cultural Heritage object itself.

For example, a raw photograph from the Kosmosoteira church in Greece, used for the creation of the 3D model

by the 'Athena' Research Center – Xanthi Division
http://europeana.eu/portal/record/2048701/object_HA_72
6.html

Type B: 3D images or panoramic photos as a 2,5D visualisation.

For example, a 3D panorama from the church for the Dormition of Virgin Mary in Makri, Evros, Greece created by the 'Athena' Research Center – Xanthi Division.
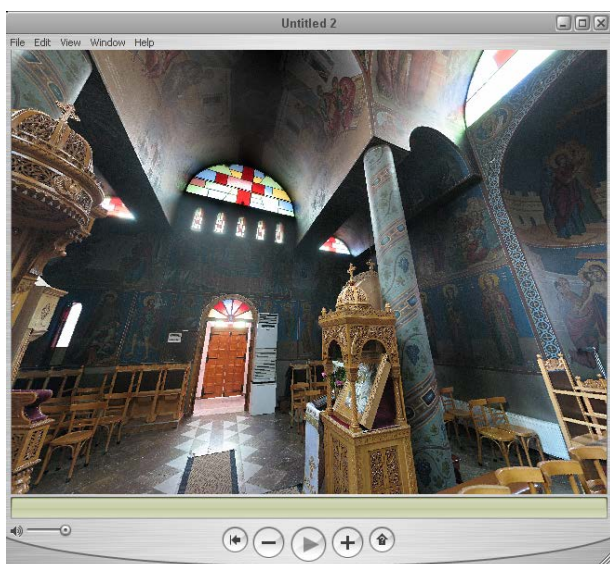
Type C: 3D data resulting from photogrammetry

Type D: 3D reconstruction of a building or object that has not survived. For example, the Parthenon Sculpture Gallery.
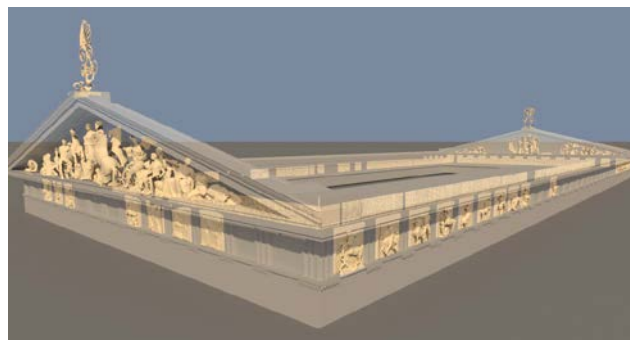
http://gl.ict.usc.edu/Data/parthenongallery/renders/overvie
w_render.jpg

Type E: 3D model of an existing building or objects; 3D model of a character as an avatar.

For example, the 3D model of the Kosmosoteira church created by the 'Athena' Research Center – Xanthi Division.

http://3d_icons.ipet.gr/3dicons/index.php?id=ARC3DICON
S_3D_1KOS&res=RAW&metadata=inactive

Type F: 3D data resulting from laser scanning, as preservation and recording method.

Type G: Virtual Research Environments or 3D Scholarly Environments.

Type H: Building Information Model (BIM) and Heritage BIM.

These eight types of CH visualisation, included in the previously mentioned structure, should be seen as preliminary work in progress. It is necessary to enhance this structure through further research, as well as verify it against earlier research and literature. It should also be discussed within the COSCH communities.

3.3.5.2. Investigation of Working Processes of Projects

The investigation of the projects in Sarajevo has identified some similar steps in creating a 3D model as a CH visualisation. These defined steps were: preparation, data collection, data processing and finishing (Figure 3.2).
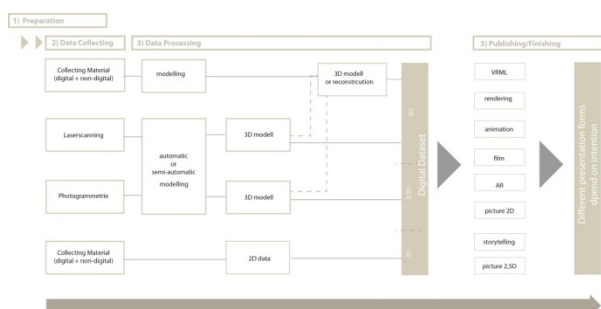
Figure 3.2: Types of CH visualisation – Sarajevo. *See COSCH WG5 Interim Report Appendix for a larger version of this diagram.*

The input-output scheme shows a clear correlation between individual steps within the four phases and linear structure.

Initial research into selected projects in London has revealed that the working processes were more complicated. Current research projects are a combination of different visualisation types and methods. Therefore, it was necessary to prepare a schema for the working process of each King's project selected.

a) Body and Mask in Ancient Theatre Space

In this project, the process consisted of eight different work packages connected in different ways. The work packages did not follow a linear order. The input or output of the work package connects the individual steps in a non-linear working process.
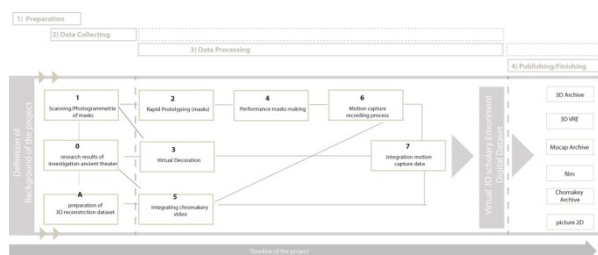

Figure 3.3: Working process or project "Body and Mask in Ancient Theatre". *See COSCH WG5 Interim Report Appendix for a larger version of this diagram.*

b) The Skenographia Project

In this project, the data processing stage was structured like a circle connecting the perspective analysis, 3D modelling and source collection. The principle of input-output happened inside this circulation, the digital datasets constituting the resulting output (Figure 3.4).

c) Oplontis Visualisation Project

The working process adopted for the project Oplontis was similar to the project Skenographia. It was also non-linear and involved a circulation and crossing between the individual work packages. A digital dataset was the result of this closed circle (Figure 3.5).

Figure 3.4: Working process of the project "Skenographia". *See COSCH WG5 Interim Report Appendix for a larger version of this diagram.*
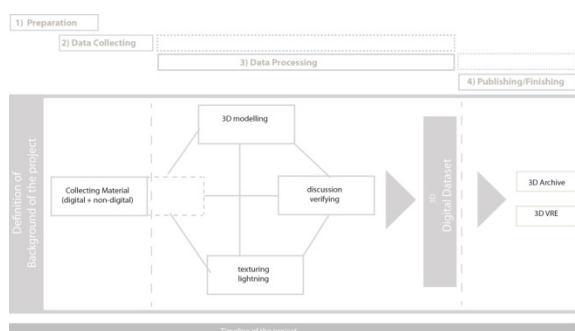
Figure 3.5: Working process of the project "Oplontis Visualisation Project". *See COSCH WG5 Interim Report Appendix for a larger version of this diagram.*

d) Roman Coins

The study "Roman Coins", currently ongoing within the COSCH Action, is different from the projects mentioned previously. The study is a survey of different methods of recording CH objects. The investigation involves the applications of individual recording techniques and after that the results are compared and evaluated. Therefore, the working process is linear (Figure 3.6).
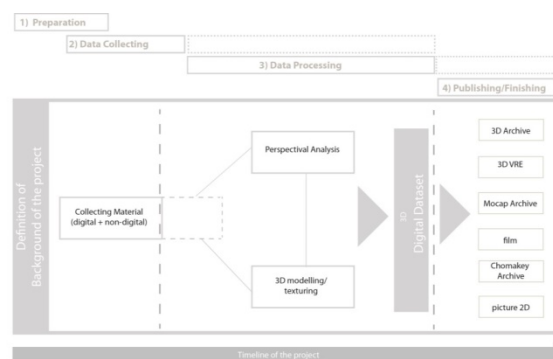

Figure 3.6: working process of the project "Roman Coins". *See COSCH WG5 Interim Report Appendix for a larger version of this diagram.*
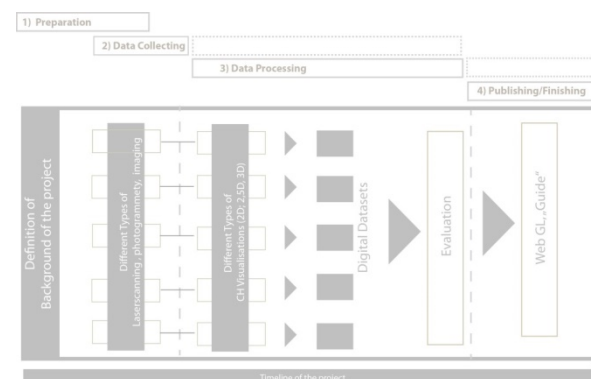
3.3.5.3. Definition of a Process as an Input-output Scheme

When comparing the different working processes of the projects at Sarajevo and London one similarity between

the workflows arises. It is possible to identify four main phases: preparation, collecting, processing and finishing (Figure 3.7).

All terms of the project – people involved, timeline, objectives, expected results, financial and other resources, as well as technical systems, which are necessary for realising a project – were determined in the preparation phase. The output of this phase generates the input for the following phase and defines the method and techniques for collecting the data.

The input of the data processing phase is based on the results of data collecting and the selected method. Within the data processing phase, the collected data could be used in different ways, depending on the project aims and objectives.

A digital dataset (2D or 3D) resulting from data processing becomes a basis for the finishing phase and the result. The possibility of different applications in different fields extends the scope of processing the digital dataset.
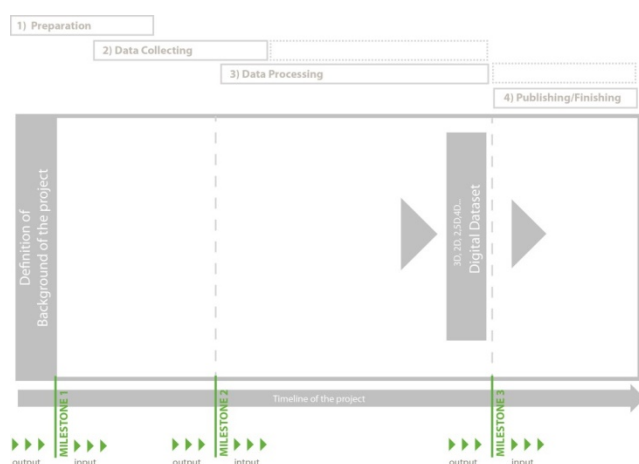

Figure 3.7: Project work frame. *See COSCH WG5 Interim Report Appendix for a larger version of this diagram.*

A principle of input-output connects the phases and the work packages. Subsequent steps interact with each other within a circular or a linear process. This further depends on the project background, aims, contributors, available techniques, schedule and funding. Therefore, these preconditions impose a framework for the project and its processes.

Three milestones characterise this framework. The first one involves the definition of the project preconditions, as identified above. They constitute an output, which forms the basis (input) for all the subsequent steps. The second milestone is the result (output) of the data collection, which in turn constitutes the input for the next phase of data processing. The resulting digital dataset (output) represents the third milestone, being the input for finishing the project and achieving the final results.

It may be necessary to identify further milestones at the outset of the project, depending on the pre-conditions specific to the project.

3.3.6. Recommendations for Future Work of COSCH

The outcome of the STSM described here is indicative of further research into 3D visualisation of cultural heritage to be carried out by the COSCH Action. It could be helpful to define typologies of CH visualisation and its applications, as a basis for COSCH[KR] Application. In particular, the defined framework and milestones identified in working processes may support the development and implementation of guidelines, or principles of the COSCH[KR] Application.

3.4. Structuring Archaeological Visualisations

Stefanie Wefers

From the very beginning of archaeological research various visualisation types have been used to represent finds, features and entire sites or landscapes in 2D, 3D, and 4D, in analogue as well as digital forms. Whereas analogue visualisations were possible from the outset and are still in use today, digital visualisation has been used ever more often, especially in recent decades (Faulstich, Hahn-Weishaupt, 2009). All visualisations can be categorised according to their veracity in relation to the physical CH object, and their interpretation and/or interpolation content. The level of probability of the correctness of the representation can be enhanced by drawing conclusions from scientific analyses (such as geomorphological analysis, pollen analysis, radiocarbon dating, geochemical analysis etc.), analogies, and experiences.

The degree of interpretation/interpolation sought differs. It depends on the purpose of visualisation and its intended audience. A layman, for example, needs more information than a subject-specialist to understand a particular visualisation and this information always involves an interpretation. The interpretation can be presented as mere text information, an accentuation (such as an arrow, a spotlight, an exaggerated colour difference), a drawing or CAD model — with or without integrated documentation of the CH object — helping the targeted audience understand a specific message.

See COSCH WG5 Interim Report Appendix, Table 1, p. 8.

4. User Evaluation of Cultural Heritage Visualisation Applications

4.1. Introduction

Positive user evaluation is the main condition of the success of virtual cultural heritage applications. Apart from the customer satisfaction questionnaires, one of the most efficient methods of user evaluation is the qualitative analysis of user feedback. It is based on interviews of users, in which they describe their experience of using the application. This kind of user evaluation is performed according to the following workflow: definition of hypotheses, interviewing the users, data coding of users'

feedback, analysis of coded answers and their comparison against the hypotheses (Figure 4.1).

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┌─────────────────────────────┐
│   HYPOTHESES DEFINITION      │
└─────────────────────────────┘
               │
               ▼
┌─────────────────────────────┐
│     USER INTERVIEWS          │
└─────────────────────────────┘
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┌─────────────────────────────┐
│      DATA CODING             │
└─────────────────────────────┘
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┌─────────────────────────────┐
│  ANALYSIS OF CODED ANSWERS   │
│  AND COMPARISON WITH         │
│  HYPOTHESES                  │
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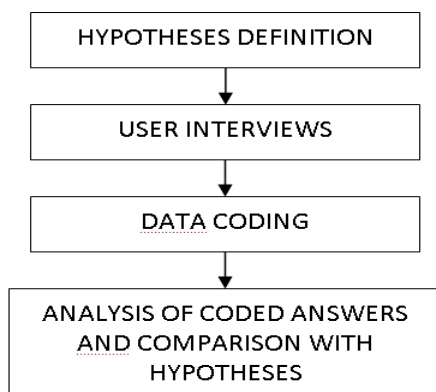
Figure 4.1. Qualitative user evaluation workflow

In this report we describe, as an example, the user evaluation of the Taslihan interactive digital storytelling project, implemented by the Sarajevo Graphics Group of the Faculty of Electrical Engineering.

4.2. Methods

Evaluation is a systematic and methodical process, where we need to ask the involved actors, and monitor the results. This is a formative evaluation: we want to learn from the results, and summative, being a continuation of the evaluation started with Bosnian national users.

Each research needs to be based on indicators, as well as feasible sources of verification. In order to obtain answers to our general objective (storytelling), we need first to discern some specific objectives. Some criteria, such as efficiency and extent, need to be considered. In order to avoid closed questions (yes/no), the questions would ideally be in the format of "to what extent...?".

The following hypotheses (H) were put forward:

- H1: Do users learn more from interactive storytelling than from linear story?
- H2: Does the interactive storytelling immerse the users in the past?
- H3: Do users prefer the interactive storytelling over the linear one?

The user interviews were designed and implemented with the following key aspects taken onto account:

- Information perception
- Immersion of users in the stories
- Appreciation of interactive storytelling

Hypotheses are formulated in order to learn about future market demands, based on the feedback of implied actors. Following a preliminary user study, with Bosnian users, we decided to obtain more information from non-Bosnian users, which would ideally not be influenced by the previous knowledge of the heritage site.

Evaluation indicators (quantitative, qualitative or mixed), were discussed. As we forecasted the evolution from criteria evaluation (as impact parameters) onto new UX evaluative approaches (a more flexible way to interview) we opted to use a qualitative scheme (open exceptionally to some quantitative-based remark).

4.3. A Case Study: The Tašlihan Project

One learns from visiting the archaeological site: the original purpose of *caravanserais* and *hans* (khan: an inn or hostel for merchants) was to provide accommodation for merchants, their wares and horses. In 1878 there were fifty *caravanserais* and *hans* in Sarajevo, of which the most important were Kolobara, Tašlihan and Morica.

Figure 4.2. The current state of the Taslihan archaeological site

The Tašlihan, also known as "the stone *han*", Husrev-bey's *caravanserai* or old *han*, was built between 1540 and 1543, in the period of greatest expansion of Sarajevo, and at the same time as the *bezistan* (covered bazaar), with which it was physically connected.

Its sponsor was the Bosnian governor and greatest benefactor of the city of Sarajevo, Gazi Husref-Bey. Unlike other *hans*, where the courtyard was designed primarily for loading and unloading goods, the courtyard of the Tašlihan contained a row of shops, making it a trading *han*. The courtyard also contained a Sebilj (public fountain) with a mosque on piers above it. It was built by artisans of Dubrovnik, and had the capacity of 30 rooms, each with its own heating system, and stables with capacity for 70 horses.

Two stone staircases near the main entrance to the *han* led from the courtyard to the rooms and landing

on the first floor. The Tašlihan was damaged by fire on several occasions, and was completely destroyed by the fire of 1879. Last remnants were removed in 1912, except for the walls next to the Bezistan (Figure 4.2).

For a basic check of perception skills:

Do you wear glasses?	Q4
Do you have any problem with hearing?	Q5

In order to proceed with research about Storytelling method, the following questions were used:

The interactive digital application is implemented in Unity 3D (Taslihan, 2015). It includes hyperlinked videos, a 3D model, ambience music, natural voice storytelling (in Bosnian language) and English subtitles (screenshot at Figure 4.3).

Figure 4.3. The Taslihan Project - introductory screenshot

4.4. Experimental Design

The user experience practice has shown that 7 users will find approximately 80% of problems of an interface or application (Seaman, 1999). User selection included different nationalities (Spanish, Indian, Azeri and Chinese) and various academic backgrounds (Computer Science, Historians, and even some Colour Science student, to mention a few). Five of them were experienced computer users. The average age of users was 29, 25 being the youngest and 32 – the oldest. We first wanted to know the users' background and familiarity with cultural heritage in question. Hence we formulated a number of questions.

Have you ever visited a virtual reconstruction of heritage? Which one?	Q1
Have you heard of / When have you heard about Tašlihan for the first time?	Q2
After having seen the presentation, can you say what is Tašlihan?	Q3

For a basic check of perception skills:

Do you wear glasses?	Q4
Do you have any hearing problem?	Q5

In order to proceed with research into the storytelling method, the following questions were used:

How interesting and engaging have you found the stories at presentation?	Q6

Did you see a common line? Do you think there is a narrative coherence?	Q7
How the music contributed to the experience? Did it help to keep the attention?	Q8 & Q9

3D model and navigation:

What do you think about 3D model?	Q10
Please tell me your thoughts about quality of model's geometry, textures and illumination.	Q11
What about the navigation through the model? and in general?	Q12 & Q13

Immersive experience:

Do you think this kind of presentation provides a deep immersion or not?	Q14
Have you felt immersed in different space and time?	Q15

Overall satisfaction of users:

Please describe what you liked and disliked in the application.	Q16 & Q17
Would you improve something?	Q18
What did you like the best in the Tašlihan application?	Q19

Impact Study:

To what extent does this presentation inspire you to know more about local heritage and history?	Q20
To what extent you agree with the following statement "architecture is the will of an epoch translated onto space"	Q21

A total of 21 questions were evaluated, some of them with several sub-levels.

4.5. Results

The results of the qualitative user study, presented here, can be summarised through a table showing whether our hypotheses were confirmed and to what extent (Figure 4.4).

Hypothesis	Percentage of confirmatory answers
H1	78.30%
H2	62.50%
H3	50.00%

Figure 4.4. Hypotheses confirmation results

The hypotheses were as follows,

- H1: Do users learn more from interactive storytelling than from linear story?

- H2: Does interactive storytelling immerse the users in the past?

- H3: Do users prefer interactive over linear storytelling?

There were some general points raised related to the user study:

50% of participants expected higher quality images, and 37% of users complained about some aspect of navigation (12% said it was too fast, and the other 25% that it was not possible to 'go' outside the building)

100% of users noted the importance of the 3D model as part of presentation. 12% remarked that it should be removed from the presentation. Regarding Textures, 80% of comments were positive. The remaining 20% recognised a good quality of the texture, but suggested using a more powerful computer, in order to have smoother movements.

25% users complained about intensity of light. Two users provided outlier values on its evaluation (too bright, and too dark) outside the mean value of "adequate" provided by the rest. 25% of users rightly noted "there is no any shadow" or "there seems to be just one illumination source".

No participant complained about narration, and just 12% complained about sound. Almost 90% percent of users complimented the use of music in the narration.

Regarding immersion feeling: 25% felt a deep sense of immersion, 37.5% a moderate feeling, and 12.5% a slight sense of immersion into the story.

12% of participants suggested that it would be good to have additional information about the ordinary life inside the building, and 12% suggested it would be better to have the presentation as part of a bigger virtual visit to the city of Sarajevo.

70% of participants, representing all categories, said that they would like to have more information, and 90% felt inspired to find out more about local heritage and history, after having viewed this presentation.

It is difficult to prove that they learnt more from interactive presentation than from a video. We can still assume from the comments received, that the participants preferred the interactive animation:

The interactive form gives freedom to select certain part of information the participant would like to listen to again.

For example, one user remarked: *I did it [the navigation] in its usual order. I stopped it several times to read subtitles, it sometimes goes a bit fast. Just in 30 seconds it does the introduction of what it is. If you don´t get the idea first time, as it happened to me, you need to start again.*

The user study demonstrated how storytelling method in general, and this presentation in particular, inspires the user more than if we were using more conventional methods, such as video.

5. Metadata and Paradata. Terminological Questions

Anna Bentkowska-Kafel

Documentation of works of art and other cultural heritage depends heavily on visual records. Without the associated description of the object (metadata) and information how the visual record has been created and conceptualised (paradata) the value of iconographic records is however limited. This is also true of 3D computer visualisation — if it is to be accepted as documentation valid for conservation, study and presentation of the object. COSCH research conducted within WG5 (including O'Shea's STSM, 2014) has indicated significant disciplinary differences in understanding key terms and concepts of heritage visualisation, its processes and purposes. These differences are often so deeply established that a conceptual and semantic consensus may not be feasible. In addition, nuanced vernacular approaches and practices are at risk of not being conveyed adequately in English, which is the predominant language of communication within the large multinational interdisciplinary COSCH community.

Figure 5.1. Graphical representation of some of the different terms used to define 3D visualisation.
Paul O'Shea, COSCH STSM 2014.

COSCH represents a wide range of interests in visualisation of cultural heritage. Visualisation is approached and understood differently, depending on one's background. For scientists involved in metrology,

optoelectronics or chemistry, for example, visualisation is a by-product of measurement data and analyses of the object physical/chemical properties at the time of survey. An archaeologist, art historian or more broadly cultural historian, is often interested in visualisation as a tool that may support the study and interpretation (sometimes hypothetical) of the object, including its original context and purpose; how the object changed in the course of history; as well as gaps in this knowledge.

COSCH scientists often refer to spatial and spectral measurements as documentation. From archaeological and museological perspectives this view is too narrow. The view of documentation in heritage domains is much broader and deeper. The challenge therefore is to bring the two distinctly different practices in arts and science closer. Past activities of WG5 (STSMs, case studies, papers and presentations, plenary discussions, COSCH KR questionnaire, etc.) have contributed to a significantly greater awareness of these disciplinary differences and particular needs, resulting in their articulation and enhanced communication.

6. Recommendations and Guidelines

Anna Bentkowska-Kafel

The COSCH WG5 promotes digital visualisation that

1) is based on accurate measurement or survey of the object; examples from COSCH case studies include 2D visualisation of chemical composition of the object and 3D visualisation based on a photogrammetric survey;

(2) includes the object metadata (sourced from the collection database, if available, or independently); metadata should be standardised, structured and as comprehensive as possible;

(3) presents all scientific data and historical sources used to create visualisation and, if possible, made them available for consultation alongside the visualisation;

(4) includes comprehensive technical metadata such as details of hardware, software and the setup, including environmental and other conditions under which the object was recorded;

(5) includes comprehensive paradata, i.e. a record of all processes and decisions involved in visualisation, both subject related and technical, so they can be examined, repeated or reviewed at a later stage.

(6) is scalable, sustainable and reusable, allowing further development production of versions of lower resolution for professional and non-professional use.

These general principles are informing good practice guides that are being developed in the course of COSCH

case studies of an ancient Greek pottery, Roman silver coins and medieval military architecture of Sarajevo.

7. BIBLIOGRAPHY

Almagro, A. 2004: Levantamiento arquitectónico. Universidad de Granada, Granada.

Álvarez, I., Lopetegui, A., Mesanza, A., Rodríguez, A., Valle, J.M., Vicente, I. 2003: "Diferentes propuestas para la representación geométrica" Arqueología de la Arquitectura, 2, pp. 9-12.

Angulo, R. 2012: "Construcción de la base gráfica para un sistema de información y gestión del patrimonio arquitectónico: Casa de Hylas" Arqueología de la Arquitectura, 9, pp. 11-25.

Antoñanzas, M.A., Iguácel P., Lopetegui, A. y Valle, J.M. 2003: "El Sequeral (Calahorra, La Rioja). Investigación fotogramétrica y arqueología" Arqueología de la Arquitectura, 2, pp. 13-16.

Apollonio, F. I., Gaiani, M. and Benedetti, B. (2012) 3D reality-based artefact models for the management of archaeologi-cal sites using 3D GIS: a framework starting from the case study of the Pompeii archaeological area. Journal of ar-chaeological Science, 39, 1271-1287.

Azkarate, A., Cámara, L., Lasagabaster, J.I., Latorre, P. 1999: Catedral de Santa María Vitoria-Gasteiz. Plan Director de Restauración (2 vols.). Diputación Foral de Álava, Vitoria-Gasteiz.

Banerjee, R. y Srivastava, P.K. 2013: "Reconstruction of contested landscape. Detecting land cover transformation hosting cultural heritage sites from Central India using remote sensing" Land use policy: The International Journal Covering All Aspects of Land Use, 34, pp. 193-203.

Baumeier, S. 2010. Entwicklung eines internetbasierten Werkzeuges zur Unterstützung von Forschungs- und Kommunikationsprozessen in der Siedlungsforschung. Untersuchung der Potentiale digitaler 3D-Visualisierungen für die Rekonstruktion von baulich-räumlichen Siedlungsstrukturen. http://hss.ulb.uni-bonn.de/2010/2075/2075.htm (16.03.2015)

Beacham, R. C.; Denard, H.; Baker, D. 2011. Virtual Presence and the Mind's Eye in 3-D online communities.

In: International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XXXVIII-5/W16. ISPRS Trento 2011 Workshop, 2-4 March 2011, Trento, Italy.

Begand, C. 2008. Virtuelle Gebäuderekonstruktion. Virtuelle Archäologie. Anwendung und Erstellung von 3D-Rekonstruktionen historischer Gebäude. Saarbrücken.

Bentkowska-Kafel, A. 2013. "I bought a piece of Roman furniture on the Internet. It's quite good but low on polygons."—Digital Visualization of Cultural Heritage and its Scholarly Value in Art History, Visual Resources: An International Journal of Documentation, 29:1-2, 38-46, DOI: 10.1080/01973762.2012.761117

Bentkowska-Kafel, A. and Denard, H., eds, 2012. Paradata and Transparency in Virtual Heritage. Farnham, England: Ashgate.

Berggren, A., Dell'Unto, N., Forte, M., Haddow, S., Hodder, I., Issavi, J., Lercari, N., Mazzucato, C., Mickel, A., Taylor, J.S. (2015) Revisiting reflexive archaeology at Çatalhöyük: integrating digital and 3D technologies at the trowel's edge. Antiquity 89, 344, April 2015, pp 433-448.

Blazeby, M. 2012. Digitising Mask Miniatures: A Life beyond a Museum Display. In: The Preservation of Complex Objects: Visualisations and Simulations. Delve, J., Anderson, D., Dobreva, M., Baker, D., Billenness, C. & Konstantelos, L. (eds.). The University of Portsmouth., Vol. Volume 1, p. 111-125

Bruno, F., Bruno, S., De Sensi, G., Luchi, M.-L., Mancuso, s. and Muzzupappa, M. (2010) From 3D reconstruction to vir-tual reality: A complete methodology for digital archaeological exhibition. Journal of Cultural Heritage, 11, 42-49.

Caballero, L. y Latorre, P. 1995: "La importancia del análisis estratigráfico de las construcciones históricas en el debate sobre la restauración monumental" Informes de la Construcción, 46, 435, pp. 5-18.

Cámara, L. y Latorre, P. 2003: "El modelo analítico tridimensional obtenido por fotogrametría. Descomposición, manipulación y aplicaciones en el campo de la restauración arquitectónica" Arqueología de la Arquitectura, 2, pp. 87-96.

Capitel, A. 1998: Metamorfosis de monumentos y teorías de la restauración. Alianza, Madrid.

Ceschi, C. 1970: Teoria e storia del restauro. Mario Bulzoni Editore, Roma.

Cignoni, P, Corsini, M, Ranzuglia, G, Meshlab: an open-source 3d mesh processing system, Ercim news 73, 45-46, 2008

Cusidó, J.A. 1996: "Aplicaciones de la termografía infrarroja y la espectrorradiometría en el estudio del deterioro del patrimonio arquitectónico nacional" Informes de la Construcción, 48, 443, pp. 15-26.

De Reu, J., Smedt, P. D., Herremans, D., Van Meirvenne, M., Laloo, P. and De Clercq, W. (2014) On introducing an image-based 3D reconstruction method in archaeological excavation practice. Journal of archaeological Science, 41, 251–262

Dell' Unto, N., Landeschi, G., Leander Touati, A. M., Dellepiane, M., Callieri, M. & Ferdani, D. (2015) Experiencing An-cient Buildings from a 3D GIS Perspective: a Case Drawn from the Swedish Pompeii Project. Journal of archaeological method and theory.

Der Manuelian, P, Giza 3D: Digital archaeology and scholarly access to the Giza Pyramids: The Giza Project at Harvard University, Digital Heritage International Congress (DigitalHeritage), 2013 (Volume:2), pp 727 – 734, IEEE, ISBN 978-1-4799-3168-2

Denard, H. (ed.) 2009. The London Charter for the Computer-based Visualisation of Cultural Heritage. London: King´s College London. http://www.londoncharter.org/.

Docci, M. y Maestri, D. 1994: Manuale di rilevamento architettonico e urbano. Laterza, Roma.

Eulalia de Bóveda (Lugo) y San Fiz de Solovio (Santiago de Compostela)" Arqueología de la Arquitectura, 5, pp. 15-32.

Fasold, P., Hampel, A., Scholz, M. (in preparation 2015) Der römische Bestattungsplatz von Frankfurt am Main-Zeilsheim. Grabbau und Gräber der provinzialen Oberschicht. Schriften des Archäologischen Museums Frankfurt am Main 26.

Faulstich, E.I., Hahn-Weishaupt, A. (eds.) (2009) Dokumentation und Innovation bei der Erfassung von Kulturgütern. Schriften des Bundesverbands freiberuflicher Kulturwissenschaftler, vol. 2, pp. 30–34. NETZpublikation.

Frings, M. (eds.) 2001. Der Modelle Tugend. CAD und die neuen Räume der Kunstgeschichte. Weimar.

Forte, M., Dell'Unto, N., Issavi, J., Onsurez, L. and Lercari, N. (2012) 3D archaeology at Çatalhöyük. International Journal of Heritage in the Digital Era, 1, 3, 351-378

Forte, M., Dell' Unto, N., Jonsson, K. and Lercari, N. (2015) Interpretation Process at Çatalhöyük using 3D. 20th Annual Meeting of the European Association of archaeologists (EAA2014), 10-14 September 2014, Istanbul, Turkey

García, F. 2003: "La técnica geofísica de ground penetrating radar (georradar) aplicada al patrimonio", en Iglesias, J.M. (coor.) Actas de los XIV Cursos Monográficos sobre el Patrimonio Histórico (Reinosa,

julio-agosto 2003), pp. 175-196. Universidad de Cantabria, Reinosa.

García-Gómez, I., Fernández de Gorostiza, M. y Mesanza, A. 2011: "Láser escáner y nubes de puntos. Un horizonte aplicado al análisis arqueológico de edificios" Arqueología de la Arquitectura, 8, pp. 25-44.

Gaitatzes, A, Christopoulos, D, Papaioannou, G, Virtual Reality Systems and Applications: The Ancient Olympic Games, Advances in Informatics, Lecture Notes in Computer Science Volume 3746, 2005, pp 155-165

Glassner, A, Interactive Storytelling. A. K. Peters. 2004.

González-Varas, I. 1999: Conservación de bienes culturales. Teoría, historia, principios y normas. Cátedra, Madrid.

Grellert, M. 2007. Immaterielle Zeugnisse. Synagogen in Deutschland. Potentiale digitaler Technologien für das Erinnern zerstörter Architektur. Bielefeld.

Hermon, S. 2012. Scientific Method, Chaîne Opératoire and Visualization - 3D Modeling as a Research Tool in Archaeology. In: Bentkowska-Kafel, A. and Denard, H., eds: Paradata and Transparency in Virtual Heritage. Farnham, England: Ashgate.

Huseinović, M, Turčinhodžić, R, Interactive animated storytelling in presenting intangible cultural heritage, In Proceedings of Central European Seminar on Computer Graphics, Bratislava, Slovakia, 2013

Rizvic, S, Sadzak, A, El Zayat, M, Žalik, B, Rupnik, B, Lukač, N, Interactive Storytelling about Isa Bey Endowment, Review of the National Center for Digitization, Faculty of Mathematics, Belgrade, ISSN: 1820-0109, Issue: 25, 2014, pp 66-74

Iglesias, J. M. (coor.) 2002: "Experiencias cartográficas y fotogramétricas aplicadas a la conservación del Patrimonio Histórico" Actas de los XII Cursos Monográficos sobre el Patrimonio Histórico (Reinosa, julio-agosto 2001), pp. 215-332. ISPRS, International Society for Photogrammetry and Remote Sensing, Reinosa.

Jablonka, P. 2004. Virtuelle Archäologie – Troja VR. Schlussbericht des Verbundprojektes „Virtuelle Archäologie" - VR basiertes Wissensmanagment und – marketing in der Archäologie – Teilprojekt Troja VR. Tübingen.

Jiménez, A., Pinto, F. 2003: Levantamiento y análisis de edificios. Tradición y futuro. Universidad de Sevilla, Sevilla.

Jokiletho, J. 1999: A History of Architectural Conservation. Butterworth Heinemann, ICCROM, Oxford.

Kenderine, S, "Pure Land": Inhabiting the Mogao Caves at Dunhuang, Curator: The Museum Journal, Volume 56, Issue 2, pages 199–218, April 2013

Keys To Rome exhibition, V-MusT.net, 2014, www.keystorome.eu

Koob, M. 1995. Architectura Virtualis. Konzept für das 1. Digitale Architekturmuseum, ein Wissenschaftsort für Forschung und Dokumentation der Kunst der Bautechnik im dritten kulturellen Weltgedächtnis. Bensheim.

Koob, M. 1995. Architectura Virtualis. Projekt Weltkulturerbe. Bensheim.

Riedel, A. u.a. (Hg.)2006. Modellieren, Strukturieren, Präsentieren. Von Handaufmass bis High Tech II. Informationssysteme in der historischen Bauforschung. Mainz.

Koutsoudis, A., Vidmar, B., Ioannakis, G., Arnaoutoglou, F., Pavlidis, G. and Chamzas, C., Multi-image 3D reconstruction data evaluation. Journal of Cultural Heritage, 15, 1, 2014, 73-79

Kraljic, N, Interactive video virtual tours, In Proceedings of CESCG 2008

Kuroczyński, P. 2015. Digital Reconstruction and Virtual Research Environments – A matter of documentation standards. In: Access and Understanding – Networking in the Digital Era, Proceedings of the annual conference of CIDOC, Dresden, 06.09.-11.09.2014; http://www.cidoc2014.de/images/sampledata/cidoc/papers/L-1_Kuroczynski_paper.pdf

Lamberini, D. 2003: Teorie e storia del restauro architettonico. Polistampa, Florencia.

Levoy, M, The Digital Michelangelo Project: 3D Scanning of Large Statues, Proceedings of Siggraph 2000

Lichti, D., Pfeifer, N. y Maas, H-G. (eds.) 2008: "Theme issue Terrestrial Laser Scanning" Journal of Photogrammetry and Remote Sensing, 63.

López-Menchero Bendicho, V. M., International Guidelines for Virtual Archaeology: The Seville Principles. Corsi, C., Slapšak, B. and Vermeulen, F. (eds.) Good practice in archaeological diagnostics: Non-invasive survey of complex archaeological sites, Springer, 2013, 269-283

Manovich, L. 2002. The Language of New Media. 1st MIT Press pbk. ed, Cambridge, Mass.

A Human Sanctuary Project, Cyprus Institute, 2013, http://public.cyi.ac.cy/scrollsDemo

Mañana-Borrazas, P., Rodríguez, A. y Blanco-Rotea, R. 2008: "Una experiencia en la aplicación del Láser Escáner 3D a los procesos de documentación y análisis del Patrimonio Construido: su aplicación a Santa

Martínez Justicia, M.J. 2000: Historia y teoría de la conservación y restauración artística. Tecnos, Madrid.

Miller, C, Digital Storytelling. Elsevier. 2008.

Münster, S. 2011. Entstehungs- und Verwendungskontexte von 3D-CAD.Modellen in den Geschichtswissenschaften. In Meissner, K. (2011): Virtual Enterprises, Communities & Social Networks. Dresden: TUDpress

Núñez, A., Buill, F. and Edo, M., 3D model of the Can Sadurní cave. Journal of archaeological Science, 40, 12, 2013, 4420-4428.

O'Shea, P. 2014. Creating and Maintaining Controlled Vocabularies for Use in Cultural Heritage Visualisation, COST TD1201 Short Term Scientific Mission Report, http://cosch.info/documents/10179/117539/STSM+abstract_O'Shea_COST+Action+TD1201.pdf/105e335d-551c-4304-b6e4-34be49a099c3

Ortega, J., Martínez, A. y Muñoz, M.J. 2011: "El dibujo y las vidas de los edificios" Revista Expresión Gráfica Arquitectónica, 18, pp. 50-63.

Pfarr-Harfst, M. 2013. Research of Cultural Heritage - Virtual Scientific Models. In: Stadtarchäologie Wien (Hg.): Proceedings of the 17th International Conference on Cultural Heritage and New Technologies. Wien - (online). http://www.chnt.at/wp-content/uploads/eBook_CHNT17_PfarrHarfst.pdf

Pfarr, M. 2010. Dokumentationssystem für digitale Rekonstruktionen am Beispiel der Grabanlage Zhaoling, Provinz Shaanxi, China. Darmstadt: Technische Universität Darmstadt, tuprints. http://tuprints.ulb.tu-darmstadt.de/2302/.

Pfarr-Harfst, M. 2013. A New Documentation System in the Context of Cultural Heritage. In: Verhagen, P. u.a. (Hg.): Across Space and Time. Proceedings of the 41th International Conference on Computer Applications and Quantitative Methods in Archaeology (CAA), Perth, Australia

Pfarr-Harfst, M. (2014) Documentation system for digital reconstructions. Reference to the Mausoleum of the Tang-Dynastie at Zhaoling, in Shaanxi Province, China. In Börner, W., Uhlirz, S., Dollhofer, L. (eds.) Documentationssystem for Digitale Reconstructions. International Conference on Cultural Heritage and New

Technologie - Proceedings. Museen der Stadt Wien - Stadtarchäologie, Wien , pp. 648-659. [Online-Edition: http://www.chnt.at/chnt-16-2011-proceedings/]. ISBN 978-3-200-02740-4

Rizvic, S, Pletinckx, D, Pescarin, S, Keys to Rome – The Next Generation Virtual Museum Event, South East European Digitization Conference SEEDI 2014, Belgrade, Serbia

Rizvić, S, Sadžak, A, Hulusić, V, Karahasanović, A, Interactive Digital Storytelling in the Sarajevo Survival Tools Virtual Environment, In Proceedings of SCCG 2012

Rizvic, S, Ferko, A, Sadzak A, A Piece of Peace in sWARajevo - Locally and Globally Interesting Stories for Virtual Museums, In Proceedings of the Digital Heritage International Congress, Vol. 2, pp. 445-446, ISBN: 978-1-4799-3169-9, October 2013, Marseille, France

Sainz, J. 2005: El dibujo de arquitectura. Teoría e historia de un lenguaje gráfico. Reverté, Barcelona.

Schedl, B. 2000. Starhemberg urbs . Ein virtuelles Modell der Burg Starhemberg in Niederösterreich. Wien (DVD).

Seaman, C.B, Qualitative Methods in Empirical Studies of Software Engineering. IEEE Transactions on Software Engineering, Vol. 25, No. 4, 1999.

Scopigno, R, Interactive Visualization for Cultural Heritage - Current Capabilities and Open Issues, In Proceedings of VISIGRAPP 2013, Barcelona

Sljivo, S, Audio Guided Virtual Museums, In Proceedings of Central European Seminar on Computer Graphics, Bratislava, Slovakia, 2012

Taslihan interactive digital story, 2015, http://h.etf.unsa.ba/han/sd/Build.html

Technische Universität Darmstadt, Fachgebiet CAD in der Architektur u.a. (Hg.)2004. Synagogen in Deutschland. Eine virtuelle Rekonstruktion. Basel.

Trizio, I. 2009: "Indagini Stratigrafiche e Sistemi Informativi Architettonici: il GIS della chiesa di S. Maria in Valle Porclaneta" Arqueología de la Arquitectura, 6, pp. 93-113.

Tsaouselis, A., Stavroglou, K., Koutsoudis, A., Arnaoutoglou, F., Michailidou, A., Tsiafakis, D. and Chamzas, C., The 3D Icons Portal: A Web tool for the dissemination of European 3D Cultural Heritage Objects.

Proceedings of CAA 2015, Siena, 30 March-3 April, 2015 (to be published)

Tsiafaki, D., An East Greek Fruitstand at Karabournaki. Kefalidou, E. and Tsiafaki, D. (eds.) Kerameos Paides: Studies Offered to Professor Michalis Tiverios by his Students, Thessaloniki, 2012, 153-161

Tsiafakis, D., Tsirliganis, N., Pavlidis, G., Evangelidis, V. and Chamzas, C., Karabournaki-recording the past: the digitization of an archaeological site. Cappellini, V. and Hemsley, J. (eds.) Proceedings of EVA 2004: Conference of Electronic Imaging and the Visual Arts, March 25-April 2, 2004, Florence, Italy, Bologna, 232-237.

Tsiafakis, D. and Evangelidis, V., GIS as an Interpretative Tool in Greek archaeological Research. Priestnall, G. and Aplin, P. (eds.) Proceedings of the GIS Research UK 14th Annual Conference, GISRUK 2006, 5th-7th April, 2006, School of Geography, University of Nottingham, Great Britain, 328-333

Tsiafakis, D., Tsompanopoulos, A., Pavlidis, G., Tsirliganis, N., Evangelidis, V. and Chamzas, C. Archiving Cul-tural Objects in the 21st century: Pottery from Karabournaki. Mattusch, C., Donohue, A.A. and Brauer, A. (eds.) Common Ground: archaeology, Art, Science, and Humanities, Proceedings of the XVI International Congress of Classical ar-chaeology, Boston August 23-26, 2003, Oxford, 2006, 419-423

Tsionas, I., Tsiafakis, D., Tsirliganis, N., Tsioukas, V., 3D GIS for the archaeological Excavation at Karabournaki, Thessaloniki. Proceedings of International Workshop on Spatial Information for Sustainable Management of Urban Areas, Mainz, Germany, 2-4 February, 2009 http://www.i3mainz.fh-mainz.de/FIG-Workshop/programme2-Dateien/TS%207.5_Tsionas_3D%20GIS%20for%20the%20Archeological%20Excavation%20at%20Karambournaki,%20Thessaloniki.pdf

UNESCO (Hg.)2003. Charta zur Bewahrung des digitalen Kulturerbes, verabschiedet auf der 32. Generalkonferenz der UNESCO am 17. Oktober 2003. http://www.unesco.de/infothek/dokumente/unesco-erklaerungen/charta-zur-bewahrung-des-digitalen-kulturerbes.html (16.03.2015)

Zamora, S.A., Pocoví, A. y Pueyo, O. 2005: "Aplicación de la prospección por georradar (GPR) a la delimitación y caracterización de estructuras arqueológicas. Ejemplo de las ruinas del convento agustino de Fraga" Geogaceta, 38, pp. 131-134.