A Decision Making Tool for Supporting Strategies of Archaeological Restoration

Case Study of Ostia, Maritime ‘Portus’ of the Imperial Rome

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Computer aided examination methods for remains of previous human societies support the study of past human behaviour, thus enriching the understanding of our culture. With mostly limited budgets, finding the most effective use for the limited resources for archaeological restoration is highly relevant for many existing sites all over the world. Sites, that need to allow visitors to safely experience archaeological heritage, even within natural landscapes. This paper illustrates an innovative method, technically using Building Information Modelling (BIM) and Virtual Reality (VR), for integrating the domain specific parameters - at all various scales - of the historical asset into one shared digital twin. To provide an effective platform for all project participants to share their knowledge, and to jointly develop the best design decision. The information is collected and displayed within the digital twin of the archaeological site, both for the communication between the specialists, and facilitating practice of the archaeological investigation, further analysis, conservative restoration and reconstruction. The case study aims at implementing this tool into the ongoing Portus project of Imperial Rome.

Keywords: Archaeological Restoration, Digital Design Support System, BIM, VR

INTRODUCTION
Examination of material remains of previous human societies supports the study of past human behaviour, enriching the values of our culture. One of the most important remains includes the ruins of historic buildings (Keay 2013). Digital tools in general, and especially Virtual Reality (VR) and Augmented Reality (AR), are very beneficial for researchers to visualize, to represent a ruined structure for conservation restoration, reconstruction and further analysis. In modern archaeology there has always been a strong synergy between latest technologies and formalized
Connecting the visual representation of the historical asset with a rich variety of analysis schemes, notes from the field, reconstruction hypotheses, temporal stratifications, etc., is one of the most effective scientific methods for organizing contents, and facilitating the user's archaeological investigation. Such investigation, generally, is based on and oriented towards the integration of multidisciplinary knowledge, which assigns different attributes and meanings to the same objects, commonly called “ruins”.

Strategic decision-making for preservation and restoration of archaeological sites deeply depends on developing methodologies, systems and tools for the efficient integration of different domains, and fostering the understanding for and between specialists in all project relevant domains (Trento, 2017).

**RESEARCH PROBLEM**

All over the world, there are many archaeological sites, facing the urgent need of managing archaeological artefacts/buildings preservation to prevent further, irreversible decay, with only limited available resources. Thus there is a strong need to identify the most urgent actions to be taken. Numerous sites, culturally relevant for the whole human kind, reside in large-scale areas. In order to optimize the available resources, a selection of the zones/artefacts must be made, in/at which interventions are advised. The analysis must take into account diverse categories of intervention: e.g. from the alterations and damage caused by biological origin, to the spontaneous growth of natural vegetation when not properly maintained, from the materials decay to structural degradation, just to name a few (Mancini, 2017).

A decision making process must lead to consistent solution for planning and further designing effective sets of interventions, oriented to artefact preservation and to human’s safety: on one side, the goal is to mitigate the risk of artefact degradation and damage and, on the other side, the goal is to allow safe physical or visual access for technician/operators during the restoration phase, as well as for visitors after the restoration. An information exchange, and dataset interoperability are basically the main vectors of this scenario, in which many disciplines converge into a shared framework that encompasses process management, domain-specific examination and digital representation, while preserving their fundamental identities (Garagnani, 2016).

So the question, driving this research is: Which methods and technologies in the context of the archaeological sites can be used to overcome the identified problems, to provide a platform for all project participants to jointly identify, and develop the best solutions within the given constraints.

**LIMITATION OF CURRENT STATE OF ART**

Over the last decades, many researchers explored the open possibilities offered by implementing advanced digital technologies in the archaeological field, with valuable results for well-defined problems (Agapiou, 2015). Following is a short résumé of the state of art regarding the aid of new technologies in the field of archaeological restoration, underling relative limitations.

Point clouds and photogrammetry are collecting very accurate information about the artefacts surface. These technologies are oriented to freeze the morphology, the shape of the artefact, in the condition at the time of the survey. They are very beneficial as one component for the research, and the development of knowledge in the field of archaeology. However the outcome is limited, only being the “simulacrum”, namely a representation of the artefact.

Agent Based simulation is used to “re-enact” and “visualize” possible scenarios for a wider (generally non-scientific) audience, based on scarce and fuzzy data (Wurzer, 2015). These technologies are often used for hypothetical reconstructions, mostly for visitors whose only experiential value is given by the spatial vision. Still it does not seem suitable to support the collaboration between specialists in different domains in the analysis and planning of the restoration (Rua, 2011).
Heritage-BIM, both has potentials and limits on specific research and application fields (Cursi 2015), since BIM is especially suited for managing standardized entities, while archaeology restoration mostly involves unique cases/artefacts.

GIS technologies are being used in archaeology as mechanisms to collect the diverse spatial data gathered in previous research. New geoinformation technologies are enhancing the recording of archaeological information, but the application in archaeo-restoration practice is still not focused on supporting the integration of different domains perspectives.

Generally, if applied in well restricted problems, point clouds, photogrammetry, agent based simulations, heritage-BIM, and archaeo-GIS can cover specific research problems. But none of them is fully suitable to support the collaborative exchange between different specialists in the planning, especially in early design analysis/synthesis and strategic decision making for restoration interventions. Improving the quality of the connections between morphological aspects (shape and form), and specialized domain information/knowledge is a focal point of this research. How to enhance reciprocal understanding between the specialists from different domains involved in the project, and how to support the strategic decision makers of the project (by providing them an intuitive synthesis dashboard) is an urgent research field for the restoration of archaeological sites.

**APPROACH**

This work illustrates a new approach, using BIM and VR tools, for assisting project participants at early phases for archaeological sites preservation and re-functionalization in large scale projects. The tools are used to support integrated analysis, combined with enhanced representation of domain specific information and visualization of diverse evaluations. Despite the evolution of archaeological mapping methodologies and techniques, a detailed mapping is essential for systematic archaeological practice. It is commonly conducted in five main stages: identification, evaluation and excavation, site preservation and documentation, analysis and interpretation, education (Pettitt 2019). Recurrent in every project is building on relevant documentation. Documentation about the whole site, individual artefacts, or even parts thereof, always in dynamic evolution, including issues e.g. from historical evaluation to georeferenced point clouds.

Our investigation focuses on the stages that come after identification, evaluation and excavation, namely the enhanced mapping of further domain specific documentation, analysis and interpretation, mainly oriented to site preservation, and to the following exhibition/education aims. The interventions needed, exemplified in the Portus project, can be categorized as follows:

- Preliminary safety operations
- Operations of consolidation of dangerous structures
- Operation of extraordinary management of green areas
- Conservative restoration of wall coverings and floors
- New visit pathway and resting spots

As a preparative step, the collaboration process between the relevant participants starts with an integrated analysis. It is performed within an enriched geometrical environment, showing both the visual appearance of the artefacts, and additional information - aiming to support multidisciplinary design teams in the identification and classification of artefacts in order to efficiently manage resources available for the project.

The idea of preserving the image of the artefact in a ruined state, showing the signs of ageing and in order to ensure the reading after restoration, lead to the adoption of different and integrated intervention strategies. Just to name few: the criterion of minimum intervention; the adoption of construction techniques and materials appropriate to the appearance of the ruins (similar, but distinguishable reintegrations); the slowdown of the degradation with punctual operations, such as water regimentation,
vegetation control, grouting operations; control of the degradation of materials and architectural structures with selected biological species and landscape tools; site management with a maintenance plan.

In order to manage the complexity behind strategic decision making for the optimisation of resources, the authors observed and interviewed the project specialists for identifying the main domain-dependent parameters, e.g. the structural-biological risks, archaeological-historical values, site accessibility, safety of the areas and of the artefacts as well as financial and time resources.

Studying a typical workshop session, the following parallel activities can be distinguished:

- Archaeologists perform the analysis, evaluate and map the most relevant archaeological artefacts to be preserved and exhibited
- Engineers perform the analysis, evaluate and map the most relevant Structural problems, also identifying the artefacts subsystem relevant for historical MEP techniques, to be preserved and exhibited (engineering cultural values)
- Agronomists perform the analysis, evaluate and map the most relevant vegetation, biological problems, also identifying relevant natural subsystems for landscape aims, to be preserved and exhibited (agronomic cultural values)
- Architects perform the analysis, evaluate and map the most relevant exhibition sight spots - nodes and connections -, taking into account the other specialist's domains such as cultural values

To reduce the number of parameters shared among all actors, details have to be filtered. Parameters have to be compared and common occurrences have to be spotted. Emphasize has to be laid on the following four main indicators:

- Cultural relevance of the artefact
- Urgency of interventions
- Typology of interventions needed
- Estimated costs of interventions

The goal of the digital system in the first stage is to assist project actors assigning domain specific values in the digital twin to the aforementioned indicators (evaluation matrices), both for each natural and artefact system/subsystem/element. These values are assigned to “Smart Labels”, a specific Revit family that can hold various types of information as described in the following paragraphs. In the second stage, these values are used for various simulations of the integrated matrices to visualize domain specific evaluations, or part of it, and envision an intuitive representation of hierarchical priorities linked to the 3D model of the artefacts.

The information is collected and displayed within the digital twin of the archeological site, both for the communication between the specialists and later for the visitors. The following chapters describe the application in a real case study, discussing the pipeline for technological implementation.

**CASE STUDY OF IMPERIAL ROMAN “PORTUS”**

The presented work is oriented to support an ongoing project, currently in an early design phase, when decisions taken, deeply affect the quality of the process and of the final results. The project aims at the restoration of selected artefacts and at the realisation of an exhibition path open to visitors for enjoying the entire archaeological landscape and its contents in the preserved area of Portus, the maritime port of Imperial Rome within the Ostia Antica Archaeological Park. The authors are challenged by studying and developing a technological framework for supporting domain specialist consultants by facilitating the integration of multi-disciplinary perspectives during analysis and design activities.

For about 500 years, Portus was the commercial hub that connected the Metropolis to the broader Mediterranean. It was a very large complex covering approximately 3.5 square kilometres and which encompassed 230.5 ha of harbour basins and quays, as well as canals, warehouses, temples, churches, houses and administrative buildings. Since it is also
one of the best-preserved Roman Mediterranean port sites, and now lies inland, it can be readily studied to learn about how it was organized and worked, the richness and volume of traffic and cargoes that passed through it, and the range of its contacts across the Mediterranean (Canina, 1838).

Digital technologies in the research work within the Portus archeological site project have been used since the last decades by Simon Keay (2009, 2013) in collaboration with the Italian Ministry for Heritage Preservation - Soprintendenza del Parco Archeologico di Ostia Antica and many prominent authorities (Ceccarelli, 2000). One promising experimentation path is combining three-dimensional geophysics with laser scans and sections of excavations to understand the development of the original site and buildings [1].

“The Portus Project has two main objectives. Firstly, it seeks to build a better understanding of Portus itself. Secondly, it aims at developing techniques that will enhance the ways in which highly complex classical sites can be investigated and recorded, and evaluate the impact of those techniques. Used in combination, non-destructive survey, open area excavation, and the computer graphic representation of excavated and graphically-simulated Roman buildings are key components to achieving these objectives” [2].

In the present application work, available resources (e.g. main artefacts point clouds), made accessible from the Soprintendenza and Portus Project archives, are addressed to consolidate and preserve a set of selected archaeological artefacts in a delicate balance with a gorgeous, but many times dangerous, natural environment. The goal is to design the exhibition path, restoring selected artefacts and ensuring the safety/comfort of operators during the restoration and of future visitors.

To identify the most necessary actions, an overall structural risk map (figure 1) was created, showing spots of interventions over the whole site. On an object level, the Trajan Terrace, structural risks were identified with a heat map (figure 2) showing vulnerability in case of an earthquake.
CONCEPTUAL AND TECHNOLOGICAL IMPLEMENTATION PATH

As there is no one software system available to integrate and communicate knowledge from the different disciplines in the required structured way, the authors develop a system combining BIM (Revit) and VR (COVISE). It supports both the storing and accessing of the discipline specific knowledge, as well as methodologies to support the communication between all involved participants from different disciplines.

Whereas in standard BIM usage, discrete physical building elements like walls, doors or windows are drawn in 3D, and are given specific properties (geometry, thermal properties, etc.), this most likely does not work for an archaeological site. In the archaeo-
logical context, this parametric system would have to geometrically represent non-standard elements, like e.g. a broken vault, artefacts of a partly broken stone wall, or a landscape with potential historic findings. A standard BIM system typically is not not able to model the complexity. Also due to missing information, e.g. if parts of the artefacts are not excavated yet. Furthermore, a substantial part of information about the archaeological artefacts are given in different representations like text, historic images, or as a link to an external website.

To overcome these restrictions, a layer of abstraction is applied. So instead of directly representing the archeological elements within the BIM system, a “Smart Label” (a specific Revit family) is used. The “Smart Label” with its simple visual representation is placed close to the artefact by any of the specialists, in plan view or in 3D on the point cloud. This can be either done in the BIM software itself or in the VR environment. This label is then linked to the inventory identifier of the archeological artefact, and then overloaded with the various domain specific informations, as well as links to further external information sources. (see figure 3)

Thus the “Smart Label” rather is a container for all relevant and different information, which then can be extracted with standard and advanced BIM methods, and used for calculations as well as a base for the visual analysis. The “Smart Labels” allow for the use of filters, search-engines, analytic algorithms, etc.

Some applied methods are:

- Finance heat map: Normalized pink/yellow heat map over the whole terrain visualizes the needed investments at certain locations
- Archaeology relevance heat map: Normalized heat map, based on the traffic light system, to visualize the position of the relevant artefacts
• Structural interventions heat map: Normalized heat map, based on the traffic light system, to visualize the urgency of structural preservation.

All involved parties and disciplines can individually or jointly explore the site in VR (e.g. Head mounted display; CAVE; etc.), either in model scale or at scale 1:1, and augment the point cloud representation with the above described extended information, in order to come to informed decisions.

Figure 5
Domain specific parameters in Smart Label

“SMART LABELS” AND EVALUATION
In order to store the domain specific informations, a speciality equipment Revit family which we call “Smart Label” is created. Copies of this family are placed in the digital twin close to each artefact, also to represent its geometric location (figure 4). Within the parameter list, the inventory number is the unique identifier for each artefact. For every discipline a set of parameters (e.g. costs, relevance, urgency) is prepared (figure 5), the values can either be set directly in Revit, in the VR environment or even in a shared Excel sheet, linked with a Dynamo script.

Once the parameters are set, their values can be evaluated from different discipline perspectives. By adding a multiplying parameters “relevance”, the required actions of each discipline can be weighted. So if for example archaeologists set a high relevance for an intervention, it might overrule the relevance set by other disciplines. Most calculations are already done in the Revit schedules, and can be enriched by coupling external data sources and calculations.

The evaluations are then interactively discussed in the Virtual Reality environment (CAVE) in the point cloud model at scale. With our bi-directional link between Revit and the VR software COVISE, changes of the parameter values in the Revit file, even changes to the calculation are updated automatically. Relevant parameters are also linked to the tablet user interface, to directly change them from within the virtual environment.

Different visualization methods are then used to represent the calculated results. Some examples are previously described heat maps, that provide a good overview over larger areas. Going more into detail, closer to the artefacts, other visualization representations like the traffic signals (figure 6) e.g. showing urgency of intervention appear to be effective.

CONCLUSION
Representation of, and planning for archeological sites due to their size, diversity, and vastly incomplete information about the artefacts, are a challenging task. Additionally the diversity of information sources like texts, external databases, or historic images are reasons why there is no standardized software available yet, which supports project teams in making informed planning decisions.

To overcome these restrictions, an approach combining BIM capabilities with VR was taken. An additional level of abstraction with “Smart Labels” was developed to make the relevant information accessible to all participants of the different disciplines in the planning team. Various algorithms and BIM methods are used to extract this information in a structured way, to foster the discussion between all project participants. Using VR (from desktop to CAVE) simplifies interaction with the model and fosters communication between all project participants.

Figure 6
Cones to visualize urgency
Figure 6
Evaluated traffic light visualization in VR model

ing point clouds in a virtual environment at scale 1:1 and overlaying them with additional information, the users perceive the site as if they were there and thus discussion focused and objective, much like in on-site meetings.

In the described prototype implementation within the large scale ancient Portus project, first promising results were achieved. However it still needs further development. Within this framework, the next step will be user tests evaluating our technical approach, and improving the overall usability.

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