Bridging Cultural Heritage Ontologies in VR Environment

A framework for querying and reasoning on the Temple of Venus and Rome restoration and documentation

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VR applied to Architectural and Archaeological Heritage has a long history: Digital models in this field are evolving from an aesthetic simulation of reality, or, rather, a representation of the visual perception, to a more complex model: an information aggregation core. The investigation presents a research panel oriented to enhance the digital survey products - point clouds, meshes, 3D models -to be used as an intelligent visual archive assigning structured knowledge contents to artefacts' geometry. The implemented case regards the Temple of Venus and Rome. Research, in progress, has been developed by the following steps: 1) Subdividing the artefact geometry into sub-regions; 2) Developing the consolidation ontology for a few restoration classes; 3) Assigning (manually) to each artefact subcomponent, namely a mesh sub-region, a "smart label" including a link to its consolidation ontology instance. The aim is to combine the potential of VR visualization with ontology reasoning systems.

Keywords: *VR, Archaeological Heritage, Knowledge-Based Design Systems, Restoration Ontologies.*

INTRODUCTION

"Co-creating the Future" of our cities, especially in the European context, is based on a deep understanding of cultural (tangible and intangible) heritage, to take into account the proper relationships between value preservation and new sensitivity, so it should start with emphasis from these aspects.

The historical/archaeological built environment is acknowledged as an important material and cultural resource that needs to be preserved. *"Charter on the Preservation of the Digital Heritage"*, defined by UNESCO (2003)[1], establishes how digital assets are worthwhile of interest and protection, as well as tools for analysis or communication.

The well-known complexity in current representation, visualization, and documentation of the historical assets leads to the problem of effective operational analysis, even more so as different actors have different artefact interpretations.

With this premise, we assume that digital technologies offer multiple opportunities to improve and expand the comprehension of existing complex artefacts.

Restoration and enhancement projects steadily depend on developing new methodologies, systems and tools oriented to foster the inclusion of different actors in and throughout the design process.

Connecting the visual representation of the historical asset with a wide variety of analysis schemes like notes from the field, reconstruction hypotheses, temporal stratifications, etc., is one of the most effective scientific methods for organizing contents and thus facilitating the investigation and restoration actors in the Architectural and Archaeological Heritage field.

The work presented in this paper is a structured contribution to the elaboration of a theoretical and methodological framework oriented to enhancing the immersive visualization experience with the computational power of explicit knowledge about the heritage artefacts and vice versa.

Methodologically, we want to support restoration design by combining Virtual Reality (VR) with Ontologies by means of linking geometry entities to multidisciplinary knowledge-based systems (KBSs) (Bille 2001).

STATE OF THE ART AND LIMITS

VR applied to Architectural, Archaeological Heritage, and even unbuilt or re-built artifacts (Sdegno 2011; 2012) has a long history: it is a union born, on the one hand, to achieve mainly functional aims and, on the other hand, to deliver applications made of pure fascination (Agapiou 2015; Garagnani 2016).

Digital models have been evolving from an aesthetic simulation of reality, or, rather, an image representative of visual perception, to a more complex model: interactive, manipulable, searchable, navigable, multi-viewable, up to information aggregation core (Keay 2009; Pettitt 2019; Rua 2011; Wells 2014; Wurzer 2015).

In the last decades many researchers explored the open possibilities offered by implementing advanced digital technologies in the archeological field, with valuable results for well-defined problems.

Following is a short résumé of state of art regarding the aid of new technologies in the field of archaeological restoration and underlying relative limitations.

Point cloud and photogrammetry collect very accurate information, and they are oriented to capture the geometric - morphological knowledge of the artifact in its condition at the time of the survey. It constitutes an initial and central aspect of the research and the development of knowledge in the field of archaeology. However, this geometrical output is the simulacrum of exclusively implicit knowledge.

Agent-Based simulation has been used to "re-enact" and "visualize" possible scenarios for a wider (generally non-scientific) audience based on scarce and fuzzy data (Wurzer 2015). It is often oriented towards hypothetical reconstructions, usable by virtual visitors whose only experiential value is given by the spatial vision, more or less immersive. Still, it seems not being suitable to support the collaboration between different specialist domains in the analysis and planning of the restoration.

Heritage-BIM has limits and potentials in specific research and application fields (Cursi 2019), since BIM is especially suited for managing standard entities, whereas archaeology restoration mostly involves unique cases.

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

Generally, if applied to well-restricted problems: Point clouds, Photogrammetry, Agent-based simulation, Heritage-BIM, and Archeo-GIS showed potentials in specific tasks and application fields but are not fully suitable to support the collaborative exchange between different specialists in the planning, early design analysis/synthesis and strategic decisions for restoration interventions, as they lack semantic capabilities.

On one side, VR technologies elicit interaction amongst the different process actors by facilitating discussion about the same geometrical entities but different semantic (and abstraction layers), accurately represented and visualized in immersive environments. One of the major VR limits is that the discussion is based on the actors' implicit knowledge, not directly processable by computers.

On the other side, KBSs allow designers to have efficient automatic support as they can store, compute, infer and manage knowledge, expertise and experiences about the same building entities. One of the KBSs main limits resides in the scarce "visual understanding" of the relational knowledge graphs embedded in the building geometry. This might be one of the main reasons for the still inferior state of KBSs in the field of Architecture and Archaeology.

We believe that supporting the humans' ability of intuition for both creativity and problem solving, we need to allow actors to work at different abstraction levels while visualizing design entities: this can be done by extending the role of automatic formal reasoning behind the geometry representation.

MULTIDISCIPLINARY RECIPROCAL UNDERSTANDING OF "RUINS"

Architectural-Structural-Archeological restoration is a multidisciplinary design-based activity. It is a purpose-oriented collective process defined in time, split up into phases, carried out directly or indirectly by numerous 'actors', and characterized by the co-presence of numerous disciplines.

Actors acquire the necessary information (books, reviews, online libraries, codes, etc.), re-process their own experiences and lay down their own design solutions. They ultimately have to interact with the other actors in such a way as to reciprocally combine their own partial solutions into the overall design solution by means of gradually developing their own partial solutions.

Actors have to correctly understand the information associated with the entities they often concurrently manipulate and that make up the overall design solutions.

Appropriate information representation and organization constitute a precious digital asset for a future restoration/re-functionalization project or a preservation/maintenance program, being acknowledged in an intuitive but structured way about the previous interventions on the artefact, both ordinary and extraordinary.

Such an investigation aims at a more general application, namely the integration of multidisciplinary perspectives, which assign different attributes and meanings to the same objects, commonly called "ruins".

It is an urgent research field for the restoration of architectural/archaeological sites how to enhance mutual understanding between the specialists' consultants from different domains involved in the project and how to support the strategic decision makers of the project - by providing them with an intuitive "synthesis dashboard". That requires the combination of different technologies, for example, Virtual Reality (VR) and Ontologies.

Combining VR + Ontologies

Improving the quality of the connections between morphological aspects and specialized domain information/knowledge is a focal point of this research. The investigation is oriented to enhance the digital survey product (point clouds, meshes, 3D models), assigning structured knowledge contents to artefacts' geometry to use as an intelligent visual archive (Trento and Fioravanti 2018).

This work is based on a structured representation of the building systems together with context, actors and process realms that have been studied - and published - by the authors over the last three decades (Carrara et al. 1992; Carrara et al. 1994, Fioravanti et al. 2009, Trento et al. 2020).

To analyze and document the historical artifact characteristics, we worked according to the following pipeline:

- Identification of the artifact point-clouds sub-regions by means of a system of placeholder,

- Representation of the couple placeholder/mesh sub-region as a new family of virtual BIM objects,

- Classification of the family instances by means of a BIM project database;

- Structuring artifact entities by linking the BIM project database to a project knowledge base organized as ad-hoc Ontology.

KBSs can allow a mutual comprehension by means of a shared ontology among actors that realizes "the ability to discuss a given topic at the same level of abstraction".

In terms of implementation toolsets:

- Point cloud "*Autodesk Meshmixer*";
- Building Information Modelling and Management (BIM) software "*Revit*";
- Ontology editor "*Protégé*".

Meshmixer is used for the digital 3D surface reconstruction and for cutting it into sub-parts;

Revit for modelling abstract-functional objects, named "Smart-label", including links to structured knowledge bases;

Protégé is used to represent Ontology knowledge bases and to organize and visualize the relational characteristics of the preserved artifact.

To combine the potentials of VR visualization with Ontologies for knowledge-based reasoning, a proper implementation pipeline has been analyzed and applied to a sample test.

Since one of the authors participated in the process management of the Temple of Venus and Rome, a restoration project, we used the available documentation as a starting point for the application of this research proposal. The Temple of Venus and Rome is one of the most important buildings in the "Parco Archeologico del Colosseo" in Rome, Italy.

In the next paragraph, we will show the implementation methodology used, the issues we tackled and possible future developments.

The implementation panel

To demonstrate the validity of this approach, we used the case study regarding the Temple of Venus and Rome (fig. 1) where, as a survey product, a point-cloud of the archaeological site, including the Temple, was available (fig. 2), and, as a design product, the documentation of the last restoration project/process was available in "traditional" form: 2D drawings, text, images and video.

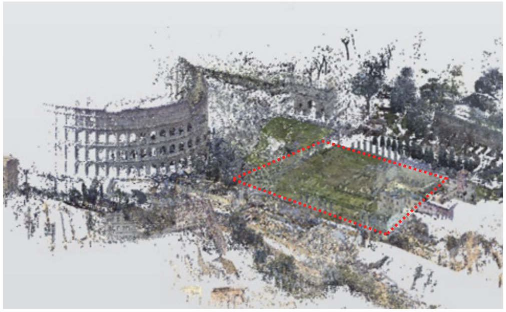


Figure 1
Point cloud of the archaeological site, including Rome and Venus Temple

Specifically, in the form of an early prototype, we represented some issues belonging to the last consolidation intervention by mapping the artifact mesh, scanned after restoration, according to 2D project drawings, explicitly linking it to the knowledge base (properly formalized) regarding the consolidation operations, that have been recently performed and documented on the field.

Implementation was done in the following steps.

1. Import the existing point cloud representing the artifact geometry into "*Autodesk Meshmixer*". Then subdividing global site mesh into regions and sub-regions according to a classification of the building "organism" subcomponent

As mentioned, our goal is to add semantic information to the geometry visualized in the VR immersive environment. To make explicit the meaning of the digital shapes representing the

Figure 2
Rome and Venus Temple point cloud explored in the VR immersive environment

artifact sub-components, we started by facing the problem of building organism classification.

Methodologically it has been developed like the Zen conception that divides Man into three parts: body-mind-spirit.

Likewise, the building can be seen as a merging of these "aspects": the Space/Technology dipole (body), the Relation Structure (mind) and Man (spirit) (Fioravanti et al. 2011).

That means a building is a living entity: the building organism.

Regarding the first "aspect", the mesh entities representing it, even though they may possess an excellent figurativeness, have no intrinsic computable meaning but merely the one it has in the cultural, scientific and professional contexts it is situated in. Therefore, the only way to give it meaning is by accompanying them with informative-explicative attachments (Carrara et al. 2009).

An answer to this practical need has been identified in the knowledge management domain, particularly in the description and usage of ontologies in this domain.

2. Develop the consolidation ontology regarding only a few restored items – the "*Protégé*" classes.

A formal" ontology within the same descriptive system includes both the concepts of a knowledge domain and the relations between these concepts [2].

This way of describing an artifact highlights the relations hidden between various types of information.

In this way, many architectural constructions belonging to the historical built environment can be documented and analyzed in innovative ways. It is important to clearly define the usage of an ontology, in addition to the comprehension of its definition. For the creation and the manipulation of ontologies, we can rely, for instance, on semantic web technologies, which include several standard ontology editors." (Di Mascio et al., 2013; Pauwels et al. 2013).

In this work, we opted for "*Protégé*".

"The ontology editors provide tools to develop ontologies and to visually represent them through graphs, and to test their functionality.

The graphic representation of the ontologies is needed for understanding the relations.

In a graph, the nodes represent the concepts, while the arches represent their relations. Instances, which are specific examples of information, can represent textual documents, images, bibliographic references, etc.

As such, "*Protégé*" provides the possibility not only to describe and visualize a knowledge domain constituted by classes, properties, instances and relations, but also to link these knowledge domains together explicitly." (Musen 2015).

The main hierarchy characteristic of the restoration classes we represented is related to the 'type' of entity: the membership 'class'.
This one is formalized as a custom-made frame structure by means of an ISA slot (Is-A).

The topology of entity assemblies represented employs a formal logic that enables us to compose an entity of a class (whole-of, or assembly of) even if from entities of different classes belonging to heterogeneous domains, for instance, the Architectural Restoration domain and the Structural Consolidation domain.

3. Assign (manually) each artifact subcomponent, namely a shape sub-region interested by the consolidation, a "Smart Label" including a hyperlink to its consolidation ontology instance.

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 archaeological context, this parametric system would have to geometrically represent non-standard elements, e.g. a broken vault, artefacts of a partly broken stone wall, a column or a landscape with potential historical findings.

Typically, a standard BIM system is 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 is given in different representations like text, historic images, or links to an external website. To overcome these restrictions, it has been applied a layer of abstraction

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, has been placed close to the artefact by any specialists in the plan view or in the 3D one, located at the point cloud). This can be done in the BIM software or VR environment.

This label is then linked to the inventory identifier of the archeological artifact, and then overloaded with the various domain-specific information, as well as links to further external information sources. (fig. 3)

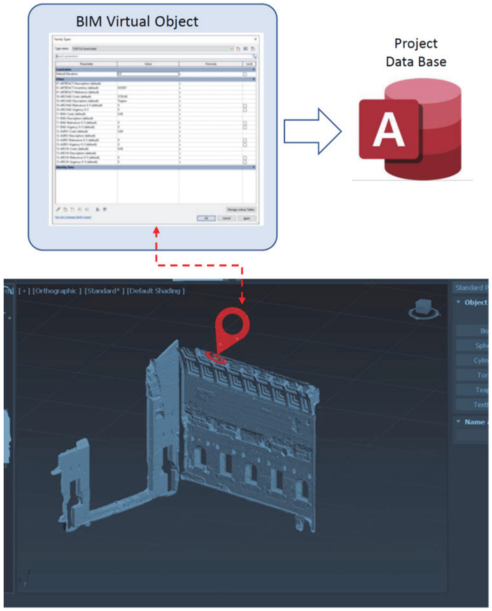


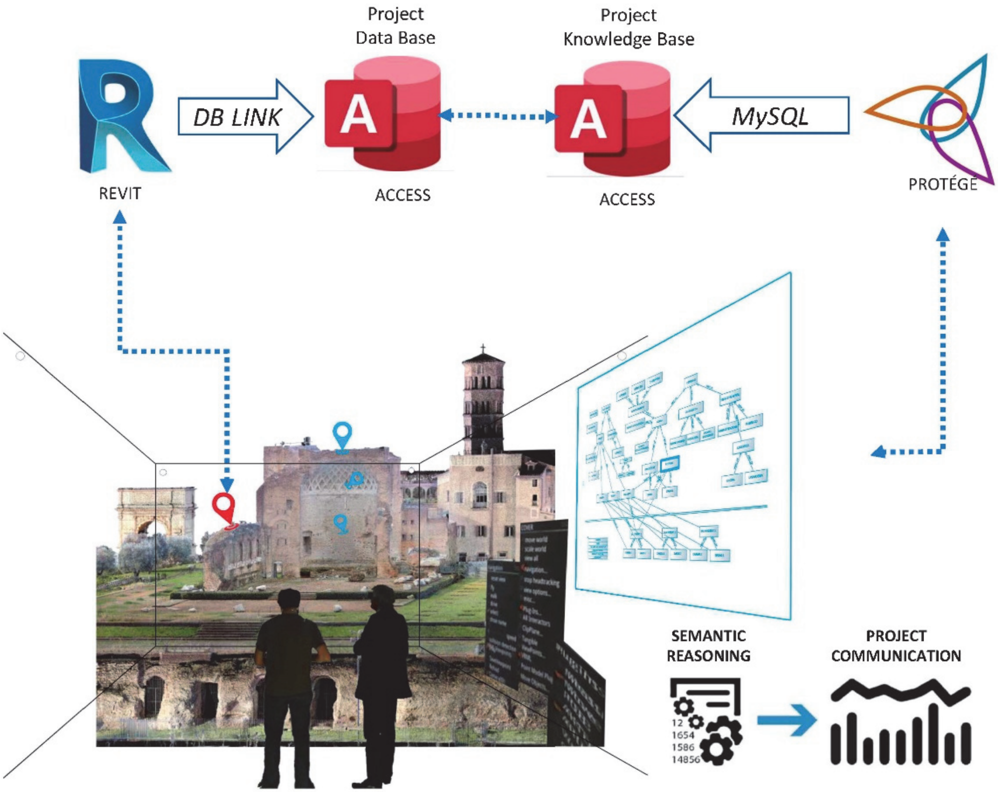
Figure 3
The smart label is organized as the inventory identifier of the artifact and includes DB links to the various domain-specific KBSs

Thus the "Smart Label" rather is a link 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", when linked to Ontology, allow for the use of filters, search engines, analytic algorithms, etc.

The Revit DB Link allows us to maintain a relationship between Revit "virtual objects", such as

Figure 4
The project toolset scenario: VR-Ontologies



Smart Labels and a database (fig.4).

We used "Revit DB Link" to export Revit project data to the Ontology knowledge database, to make changes to the data, and to import it back into the project.

The database displays Revit project information in a table view that we – manually -edited before importing.

"This table view also allows us to create Revit *Shared Parameters,* which adds new fields for those parameters in the related tables. Any change, made to these new fields within the database, updates Revit Shared Parameters upon future imports." [3]

Semantic representation of interactive 3D content gains increasing attention due to possibilities of high-level domain-specific content description, inference of hidden knowledge as well as exploration of content on request with semantic queries.

More generally, bridging the digital twin, intended as the accurately mapped mesh geometry to the artifact ontologies, facilitates the user to access - starting from a visual analysis in the VR environment - the archive of structured information according to the domain of interest.

TECHNICAL IMPLEMENTATION PLANS

Currently, the link VR to Ontology requires manual intervention. In the next step, we plan to semi-automate this by using ifcOWL, a Web Ontology Language (OWL) [4] (Pauwels and Terkaj 2016). However, the nature of IFC, rather than being a static exchange format, limits the possibilities for a living bi-directional link. Additional interaction methods in VR will then be implemented to overcome this to a certain degree. Nevertheless, this will be the focus of further research.

CONCLUSIONS

Improving the quality of the connections between morphological aspects and specialized domain information/knowledge is a focal point of this research.

The presented innovative approach deals with a more effective visualization of a multi-dimensional knowledge-based model.

We illustrated a method for enhancing the restoration design digital process by combining Virtual Reality (VR) with Ontologies by linking geometry entities to multidisciplinary knowledge-based systems (KBSs).

Interpretation is not an automatic process but rather a task that the design actor has to perform by looking at the available information. That is why visualization, together with formal representation, is the key here: it allows actors to understand quickly and accurately the output of the data mining process.

Such a representation showing ontologies, constraints and design processes – in a visual way – helps actors in better understanding the meanings of each entity according to the personal representation s/he chooses.

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