Extended BIM: a proposed workflow for the integration of the HBIM and EM approaches

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Abstract – **The present research proposes the beta version of a workflow which aims at linking HBIM and Extended Matrix using Open-Source coding and visualisation tools. The developed workflow was tested on a significant case study, the Roman Theatre of Terracina, whose excavation works started in 2019 and were initially documented through an integrated Terrestrial Laser Scanning (TLS) and Unmanned Aerial Vehicle (UAV) digital survey. In 2021 and 2022 the excavation data were updated, also using Simultaneous Localization and Mapping (SLAM) technology, thus the proposed approach focuses on the systematisation of the analysis and processing of the data regarding the consecutively surveyed excavation phases.**

I. INTRODUCTION

The built heritage is the product of the transformations that characterise it over time. That is why experts from different fields, such as architects, engineers, archaeologists, and historians work interdisciplinary to determine the historical sequences, materiality and pathologies affecting architecture. Indeed, the documentation process – whether for the purpose of mere knowledge or for the preservation and restoration of the heritage asset – becomes increasingly complex, requiring interdisciplinary coordination to build a reliable and unified database for heritage management [1].

Although the use of Information Systems in the Architecture, Engineering, and Construction (AEC) sector is renowned, the implementation of Building Information Modelling (BIM) – which relies on three fundamental aspects: parametrisation, linked information, and object-oriented modelling [2] – for the management of Cultural Heritage is still at an experimental stage. Indeed, during the last fifteen years [3], many researchers have worked in the field of the so-defined Historic Building Information Modelling (HBIM) [4]. The HBIM methodology involves customisation of the BIM technology to the existing built heritage for organising data in a coherent way within the framework of a digital information system that stores them

within a virtual 3D model [5]. As a matter of fact, the main challenges of HBIM concern meeting the requirements of the Level of Information Need (LOIN) – as defined in European legislation ISO 19650-1:2018 [6] and adopted in Italian UNI EN 17412-1:2021 [7] – as defined for new constructions, due to the extreme irregularity of the geometries of the case studies, which often show a rather deteriorated state of preservation, and the difficulty in collecting, organising, and archiving non-graphical historical data. In recent years, the HBIM methodology has also been employed for managing archaeological heritage (for example, for generating an immersive environment for advanced virtualisation [8], for setting up an open BIM type of platform aimed at data sharing [9], etc..). The proposed workflow's novelty consists of establishing for the first time a 'dialogue' between two information systems – the Extended Matrix (EM) and HBIM – via an algorithmic approach that employs open tools – *ad hoc* VPL scripts developed in Dynamo for Revit.

In recent years, within the research field of archaeology, a cutting-edge methodology has been formalised and developed with relevance to data management, data representation, and data sharing. The Extended Matrix (EM) method is an Open Science project [10], [11], developed by the DHILab of the CNR-ISPC of Rome and the Extended Matrix community, which aims to deploy a complete framework, the so-called Extended Matrix Framework (EMF), useful to manage, edit, represent, and share archaeological documentation (text, images, 2D drawing, 3D data, measure etc..) for scientific analysis and virtual reconstruction of contexts and artefacts within a 3D environment, both local (within Blender) and online (throughout EMviq) [12].

A. State-of-the-art and paper scopes

Upon working with information systems, current literature reports several experiments have been carried out concerning interoperability between software environments, different for reference scale (such as BIM vs GIS) and field of interest (e.g., architecture vs

archaeology). Additionally, researchers are currently working on adapting Information Systems, typically belonging to the AEC sector, such as GIS [13] and BIM [14], to meet the requirement of archaeological excavation works. Furthermore, a topic with particular interest focuses on the implementation of Free and Open-Source Software (FOSS) for data sharing among different types of stakeholders; namely, in the field of BIM, the most commonly accepted Open Standard is IFC, although the full compatibility of its definitions with the requirements for the digitisation of Cultural Heritage is still far from being met [15], [16].

At the moment, a selected number of projects adopted the FOSS framework to realise HBIM open source focusing on archaeology. In particular, a recent study applied to the research field of archaeology has proposed a workflow for managing entire HBIM projects completely based on Open-Source software [14].

In this regard, the present work aims to present the beta version of a workflow which establishes a connection between the HBIM methodology (used in the information model developed in Autodesk Revit, focused on the architectural aspect) and the Extended Matrix methodology (mainly developed for the Open Source software Blender, focused on the archaeological and reconstructive aspects) through the configuration of parameters and visual filters, thus setting the basis for defining an interoperability protocol aimed to bridge the gap between two different fields of expertise.

The case study is the Roman Theatre of Terracina (Latina, Italy), whose construction dates to the first century BC. It is located in the "Foro Emiliano", currently called "Piazza del Municipio", an area widely stratified by its various transformations over time. Several urban archaeological excavations were carried out; hence we attempted to systematise the analysis and the processing of the excavation phases recorded via successive surveys into a single model initially developed within the Autodesk Revit software environment starting from the archaeological monitoring data.

After Section I, which includes a brief introduction, a panoramic concerning the state of the art of the topic HBIM-FOSS, and the scopes of the contribution, the paper has been organised as follows: Section II illustrates the results of the research; Section III describes the case study where HBIM and EM has been applied; Section IV presents the EM (method and framework) and the coding approach that allowed to connect two different 3D environments (Revit and Blender); Section V and VI define the final part of the paper, where results are discussed and some considerations regarding the research are reported.

II.   RESULTS

The initial HBIM model has achieved a Level of Development C (defined object) [17] according to the Italian standard, which corresponds to the LOD 300 proposed by the American Institute of Architects (AIA) [18].

Starting from the parametric model, at this early stage, we focused on establishing a dialogue between the two information systems by defining a prototype exchange protocol organised into the following three main steps (Fig. 1).
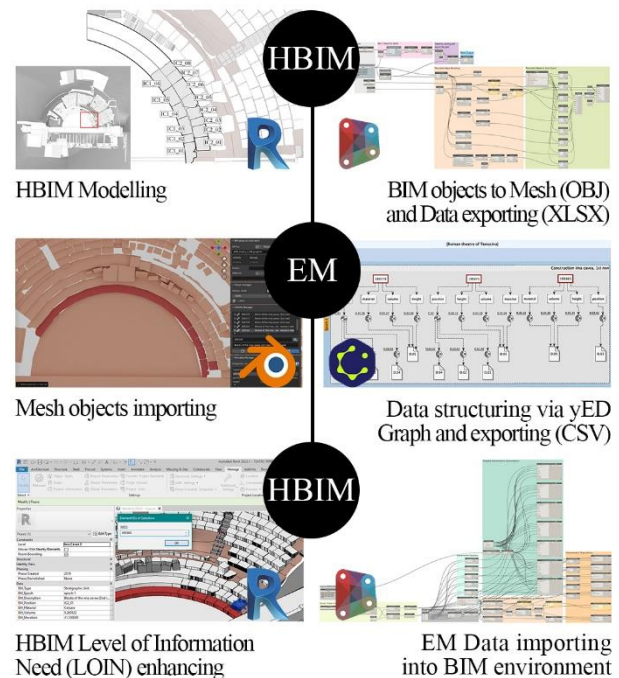

HBIM Modelling

BIM objects to Mesh (OBJ) and Data exporting (XLSX)

Mesh objects importing

Data structuring via yED Graph and exporting (CSV)

HBIM Level of Information Need (LOIN) enhancing

EM Data importing into BIM environment

Fig. 1. Diagram summarising the proposed workflow.

The first step concerns BIM object exportation together with linked information. In detail the following properties are gathered:

- The Revit object internal ID ("Name – REVIT ID"). Not to be confused with the GUID assigned to the modelled objects in the IFC data scheme, the Revit internal ID is uniquely assigned to each element within a document upon its generation and is not reissued later on, thus making it suitable to be used as a sorting key;
- The "survey phase" documentation;
- The "reference level";
- The relative "elevation" (when existing) of the object reference level;
- The element "type";
- The element "family name";
- The "area" (for those elements realised as an extrusion of an assigned perimeter, i.e., "floors" and "walls")
- The "volume"

The second step of the proposed workflow concerns Data structuring within the extended matrix environment using as a basis the BIM model and the related exported data exported separately

Finally, the third step deals with *ad hoc* generated parameters and their population within the Revit

environment. Specifically for the parameter population both Revit internal information – which are in some case hidden, are explicited so as to provide a direct access to them – and imported data derived from the EM are employed. Therefore the following new parameters are generated and placed under the "Data" properties' group:

- The Revit internally computed "Volume" and
- The Revit relative "Elevation"
- The "EM_Type" (e.g., "stratigraphic unit"), "EM_Epoch" (e.g., "epoch 1")
- "EM_Description" (e.g., "Blocks of the ima cavea – 1st row")
- The coded "EM_Position" (e.g., "IC1_01")
- The "EM_Material" (e.g., "Calcare").

For the first and the third steps of the proposed workflow, *ad hoc* Visual Programming Language (VPL) scripts were developed within the Open-Source plug-in Dynamo for Revit environment.

The mutual connection between Revit and Blender has been made possible by using geometries' ID – authomatically and uniquely assigned by the Autodesk software – as an "external key". This link between different types of information allows the error-free exchange of data and paradata, such as 3D models and their attributes (ID, position, material, location, etc.).

The test has demonstrated the possibility of mutually exchanging data from an HBIM environment (such as Revit) and the Extended Matrix (EM), a formal language, expressed as a graph of knowledge, developed to manage archaeological documentation and virtual reconstruction information. At this trial stage, the connection between HBIM and EM has been tested with a selection of geometries compared to the entire HBIM project of the Roman Theatre of Terracina. From the HBIM environment, geometries, and information (dimensions, position, location) have been exported respectively as OBJ and XLSX files and manually imported within the EM graph, realised in yEd. Within Blender, using the add-on EMtools, it has been possible to both inspect geometries, data, and paradata related to the Theatre and export the same information as a CSV file in order to be imported, in their extended version, within the HBIM environment.

Within EMtools, in order to inspect both paradata information of the reconstructive process and the ones related to the documentation process, the latter more similar to the information collected during an HBIM workflow, "Paradata inspection manager" tool has also been activated for the US node (the so-called: Stratigraphic Unit node), that is the node of the Extended Matrix palette which represents the state of the art of a structure, a portion of a structure, a context, etc.

The trial also included the visualisation of 3D models, data and paradata within EMviq (Extended Matrix visual inspector querier), a 3Dweb-app developed within the DHILab of the CNR-ISPC of Rome [19]. This web-app, which is officially part of the EMF, permits to easily visualise, present, inspect and share online 3D scenes where 3D models are enriched with data and paradata. Moreover, after the implementation of the third stage of the proposed workflow, an HBIM model whose Level of Information Need (LOIN) concerning some archaeological requirements has been increased by means of user-defined parameters, therefore, allowing to generate dedicated schedules for object filtering and project management, as well as making it possible to export such added properties as inherent features when required to share the BIM model in an open format (IFC).

III. CASE STUDY

Terracina is a city located in the region of Lazio, in the province of Latina. The city presents several Roman archaeological remains of the complex (i.e., the Theatre, the forum, etc.) and infrastructures (i.e., the *Via Appia*), which testify to its past.

Although knowledge of the Roman Theatre dates back to recent years, after the bombing of 1943 during World War II, the complex remained neglected until an archaeological research and restoration plan was put in place in the early 2000s, which required the stratigraphic removal of modern buildings. In order to document all the changes and to be able to carry out a restoration project, the excavation and cataloguing works of this urban centre continue to this day.

A. Excavations and survey phases

In 2019, demolition and excavation works started as urban archaeological interventions at the request of the *Soprindenza Archeologia, Belle Arti e Paesaggio* (SABeAP), when the Department of Civil Engineering of the University of Salerno was tasked with carrying out an integrated digital survey of the excavation works in order to monitor the entire process.

The 2019 survey was carried out via Terrestrial Laser Scanner (TLS) and Unmanned Aerial Vehicle (UAV) technology (employing a CAM 2 Faro Focus and a Leica BLK 360° for the LiDAR acquisition and a Mirrorless Sony Alpha 6500 mounted on an assembled Hexacopter for the UAV ones) to also produce orthoimages of the site and the façades [20]. Additionally, in 2019 and 2021, CAD drawings were developed as a support tool for the restoration project. Eventually, the digital survey was updated in 2022 using SLAM technology (employing a GeoSLAM Zeb Horizon with a 100 m range and a maximum acquisition speed of 300,000 points/sec). The survey database was initially systematised by developing a phase-based HBIM model of the Terracina Theatre within the Autodesk Revit environment (Fig. 2).

IV. MATERIALS AND METHODS

"Scan-to-BIM" is a reverse-engineering process involving Realty-Based 3D models (i.e., LiDAR and photogrammetric point clouds) used as a reference to manually or, possibly semi-automatically [21], develop an

information model suitable to be used for monitoring and scheduled management of a building, particularly focusing on the digitisation of Cultural Heritage.

Overlaying all the surveys carried out in the period 2019-2022, the elements that make up the various parts of the Theatre complex have been modelled in Autodesk Revit: the blocks that form the steps and stairs of the *Ima* and *Media Cavea*; the complex shapes of the galleries on both sides of the *Orchestra*; the walls that made up the *Pulpitum*; and the structures of the *Scaenae Frons*, the decorated architectural backdrop of the stage.
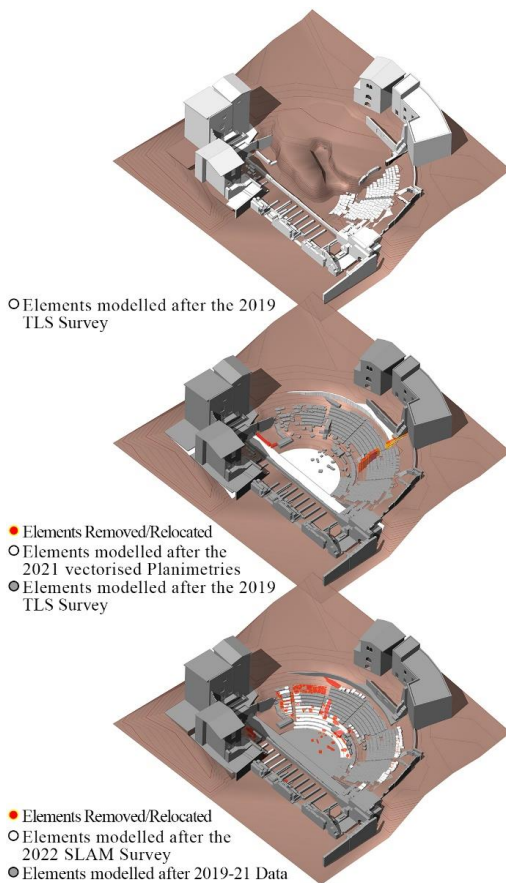

Fig. 2. Overview of the modelled excavation phases.

A. EM methodology

EM is a node-based formal language that allows graphically mapping and visually representing data provenance, i.e., the sources used within a virtual reconstruction process and its reliability "degree". Even if EM was initially conceptualised for supporting reconstructive workflows, thanks to its versatile approach (due to its Open-Source core), it has also been used for handling and tracing data provenance and data quality in archaeological documentation. EM manages chronology, by means of stratigraphy, using the general rules of the Harris Matrix, the graph that allows to represent the stratigraphic sequence of an archaeological context. The

EM Framework has a strong connection with the Open-Source ecosystem; during these years, Open-Source software solutions (such as EMtools, EMviq, 3DSC) have been developed in order to manage different tasks of research in which EM is applied (such as data managing of archaeological sources, online sharing of both 3D models and related information, and editing of survey data). EMTools is a Python-based add-on that allows inspecting and representing reconstructive data while modelling within Blender. In this case, EMTools enables the user to differentiate the data collection step – which can be carried out by cultural heritage experts – from the 3D reconstruction phase – which 3D modellers can carry out. Thanks to this tool 3D modellers can create virtual reconstruction using information collected within EM graph by cultural heritage experts without physically being in the same place.

A recent improvement of EMtools (1.4 dev version, still under development but available for testing) makes it possible to connect Blender with an external table directly. Within a virtual reconstruction process, this new feature consents to control and manage, while modelling in Blender, a complete list of documents/sources stored within an external table (as already explained, these data are analysed and listed especially for reconstructive purposes).

B. VPL Coding to connect the HBIM and the EM information systems

As previously mentioned, the gap between the two involved information systems has been bridged by means of two *ad hoc* developed VPL scripts first tested in the present case study. Visual Programming Language (VPL) provides a user-friendly interface for algorithm and parametric modelling based on nodes connected via string with an Open-Source approach that additionally allows for monitoring the script execution during the debugging process [22].
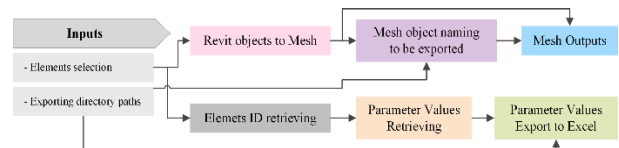

Fig. 3. Diagram breaking down the VPL script developed for the HBIM-to-EM data export – step (1).

It is worth mentioning that, albeit being data-lossy in terms of BIM properties, a mesh format – in this case, OBJ – had to be employed as a bridge between one BIM and one non-BIM software environment, simultaneously exporting to a spreadsheet the information 'lost in translation'. In detail, the outputs of the first VPL script (Fig. 3) are the selected BIM objects generated as mesh (OBJ), each named using the unique Revit identifier, which is also transferred to the first column of the data exported from Revit to a Microsoft Excel spreadsheet. In detail, The Revit ID is used as a filtering key to sort out both the imported (second script)

and the exported (first script) properties in terms of parameter values of the respective modelled objects.

BIM data, such as "Reference level", "Type Name", and "Family Name", allow to assign the correct coded position to the "stratigraphic units" in building the EM, particularly in the case of "in-place" modelling if the singular Revit instances have been modelled accordingly. On the other hand, although it is feasible to derive the material composition of the BIM objects, specifically for the system family's elements – i.e., elements whose category is "Floor" or "Wall" – their layered structure (also defined as "Compound Structure") and the consequent possible assignation of more than one material to each instance further complicates both the data exportation and the "Material" parameter values setting up upon importing such characteristic back to the HBIM environment. For said reasons, the description concerning the components' materiality has been tentatively defined for now as an additional "textual" parameter other than a proper editable Revit "Material".

Furthermore, as previously mentioned, the second script (Fig. 4) fulfils two sequential functions, the first is to generate user-defined parameters, while the second is to populate those parameters by combining both imported data – i.e., "EM_Description", "EM_Epoch", "EM_Type", "EM_Position", "EM_Material" – and intrinsic properties of BIM objects that are not always explicit – i.e., "EM_Volume" and "EM_Elevation" obtained from "reference level" and the possible offset of the modelled objects from it (if existing) –, compiled under the "Data" group of instance parameters.
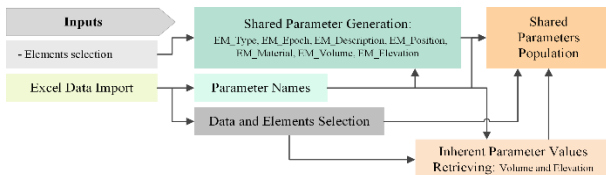

Fig. 4. Diagram breaking down the VPL script developed for the EM-to-HBIM data import – step (3).

V. DISCUSSION

As a result of the implementation of an HBIM protocol, a model has been achieved regarding the archaeological context of the Theatre, in which the chronological surveys of the interventions (2019-2022) can be distinguished through visual filters that facilitate their reading and recognition, as well as the position and possible relocation of architectural elements.

Regarding the VPL scripts developed and first tested on the Roman Theatre of Terracina, it appears clear that, albeit working without producing any recorded error, they still require further testing and optimisation before stating their universal applicability upon any HBIM-EM framework. However, the case study of Terracina represents a real possibility to test the mutual connection between an Open-Source framework (EMF) and an HBIM platform

(Fig. 5). In this case, both geometries and paradata have been successfully exported and imported from Blender to Revit and vice versa. The advantage of this approach is evident from a collaborative teamwork perspective, where different types of experts are involved in a project.

The pipeline explained in this paper demonstrates that within documentation and reconstructive process, HBIM information can be managed by an Open-Source Framework as the EMF and, thanks to the generation of user-defined parameters, also exported to an open exchange format, such as the IFC, storing all the archaeological subsequently embedded data.

Future development will face the possibility of automatically converting HBIM data – such as tables designed ad hoc via VPL scripts – in EMgraph, to manage datasets without any limitations in terms of geometries, data, and paradata.
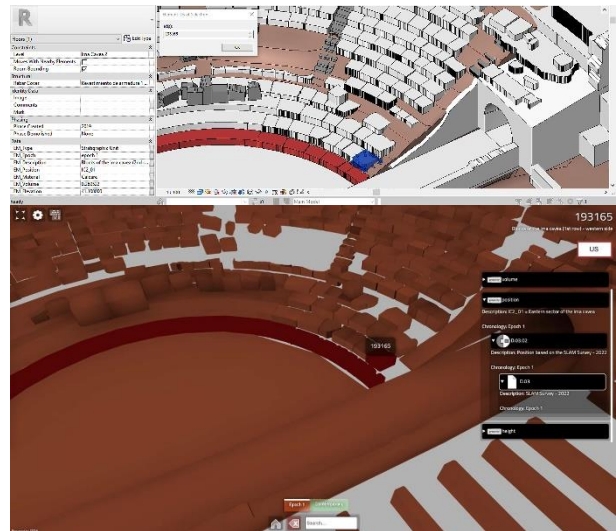

Fig. 5. Extended Matrix data visualised within the HBIM platform (Upper) and the EMviq 3D web-app (Lower).

VI. CONCLUSIONS

The case study of Terracina allows to experiment both data import and data export from and towards HBIM and EM. As already mentioned within the discussion, this research highlighted both pros and cons that suggest improvements for future releases. For instance, it would be valuable to develop within Dynamo an automatic or semi-automatic procedure to improve the connection between HBIM and EM. Another option could be the development of a stable version of a standalone tool that could manage both the import and the export of data between HBIM and EM.

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