Semantic HBIM approach for digital inclusion

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In recent years, the practice of using laser scanners or other technologies to create point clouds describing historical artifacts has become consolidated. The purpose of these surveys method is to carefully inspect architectural heritage elements. In this contest, H-BIM approach associates the geometric objects derived from these surveys with information useful for various fields (e.g., the maintenance or history of the elements). In this contribution, an analysis is made of the data required to use BIM models in extended reality (XR) applications to optimize the data accessibility for several end users (e.g., museum visitors, frails people).

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Accessibility; Data extraction/analysis; Segmentation and semantic representation; Algorithms- Retopology; SCAN-to-BIM/HBIM

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INTRODUCTION

The contribution presents a methodology that allows the creation of XR applications with BIM models in game engine environments. The models are created using heterogeneous data and evaluating levels of informative and geometrical detail depending on the user's needs. The aim is to define a methodology to develop HBIM digital models with a semantic approach. The interdisciplinary academic study on Palazzo Carignano aims to implement re-topology methodologies of historical artefacts and existing architectural elements and to transform them into HBIM elements in VR environment. Palazzo Carignano was built at the behest of Emanuele Filiberto of Savoy-Carignano, who began construction in 1679. Later, the central elliptical hall located in the 17th-century part, already used for festivities, was transformed into the chamber of the First Subalpine Parliament in 1848. As Palazzo Carignano was built between the 17th and 19th centuries, the architectural documentation lacks excellent accuracy. For this reason, it was necessary to carry out surveys with laser scanner technology in order to supplement the architectural documentation with more reliable data. The correct translation from scans to objects is not obvious and the use of Machine Learning (ML) can help during the elaboration. Data required for the model implementation varies, depending on its purpose. Thanks to the development of XR applications for the knowledge of architectural heritage, it will be possible to promote the accessibility of building spaces and documents according to the idea of inclusive design.
The research conducted by Fonseca et al. (2018)1 claims that the accessibility of cultural assets and supportive educational environments are fundamental rights for all individuals. As one of the primary public educational environments, museums must be accessible by everyone. The primary question of this article asked is "How can XR technologies be improved and developed for the diverse people in modern museum practices?" and seeks through an answer in a methodological way. As an approach for inclusive design for museum environments, the XR applications are considered as useful tools. Bedford (2010)2 mentions that the narrative or storytelling is applied for museum design because it fosters a sense of connection between visitors and the information. The XR environments are seen as a way for storytelling, which can be diversified for various user types. In this regard, this article research into improving the methodology of constructing XR environments for museums, based on the case study of Palazzo Carignano.

BACKGROUND

The use of the Building Information Modelling (BIM) methodology (BuildingSMARTalliance, 2007) for representing built heritage takes the name of HBIM and can serve various purposes. As demonstrated in (Argasinski & Kuroczynski, 2023) one of the primary reasons for reconstructing HBIM models is to preserve cultural heritage and its representative historical documents. Laser scanner technologies, as shown in (Barazzetti, 2016) are undoubtedly the most effective way to accurately represent the geometries that describe the complexity of historic buildings.
The translation of point clouds into HBIM information models can be optimised by following semantic artificial intelligence algorithms that support the identification of compositional elements of buildings (Croce, Gabriella, Andrea, Livio, & Philippe, 2023) These technologies allow us to derive the necessary parameters for precisely reconstructing complex geometries from such surveys. The precision of the survey, coupled with the informative representation of the building, enables the use of these models for purposes beyond digital heritage conservation, such as structural analysis. The article (Gonizzi Barsanti & Guidi, 2018) illustrates how geometries derived from point clouds can be used in finite element static calculation programs. This is achievable through retopology processes, i.e., using algorithms that simplify geometries, thereby reducing the number of vertices and file sizes without losing the defining details. As indicated in (Mayer & Wartzack, 2023), these algorithms can operate in various ways, more or less automatically, aiming to optimize specific functions. In this contribution, we will optimize the number of faces.
Although point clouds are the most precise tool for reliably reconstructing the complex elements of a historic building, the process of cleaning and dividing architectural elements is time-consuming. For this reason, we decided to apply certain machine-learning algorithms to expedite the segmentation process. There are already examples in the literature of applying these algorithms to point clouds. As demonstrated in (Spina, Debattista, Bugeja, & Chalmers, 2011), the application of Random Sample Consensus (RANSAC) allows for the interpolation of the point cloud with simple geometries such as planes or cylinders, thereby automatically or semi-automatically identifying the main architectural elements. Another interesting example is provided in (Czerniawski, Sankaran, Nahangi, Haas, & Leite, 2017), where the authors, in addition to RANSAC algorithms, use Density-Based Clustering (DBSCAN) algorithms to identify and classify planar elements of a building. This approach to using the Big Data contained in point clouds can significantly streamline the cleaning process, thereby expanding the range of time-saving applications that utilize survey data.
The aim of applying the afore mentioned concepts within the scope of HBIM is to utilize digital models for extended reality experiences. Extended Reality (XR) is a comprehensive term that encompasses both augmented reality (AR) and virtual reality (VR) (Hui-Wen Chuah, 2019). The XR Continuum (Milgram, Takemura, Utsumi, & Kishino, 1995) necessitates the employment of innovative technologies to eliminate communication barriers and design tailored User Experiences (UX). This

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approach can provide solutions to potential issues that may arise in daily life, particularly within historic buildings. VR can be perceived as a novel form of Human-Computer Interaction (HCI) that offers experiences and knowledge to transcend the barriers imposed by perceived reality. With the aid of Machine Learning (ML), the reconstruction of virtuality from point clouds becomes more efficient and quicker, ensuring a better match with the morphology of real environments. Additionally, retopology techniques are employed to optimize geometries for XR experiences.
To use HBIM models efficiently for XR experiences, it's essential to establish a link between the model elements and the museum data that need to be delivered through these experiences. This link can be established semantically, as demonstrated in (Moyano, Leòn, Nieto-Juli´an, & Bruno, 2021) where the authors leverage the inherent semantics of BIM informative models and the concept of ontology to enhance interoperability among modeling software.

METHODOLOGY

The methodology developed starts from the utilization of heterogeneous data to construct a BIM model that will enable the loading of diverse content based on the type of virtual or augmented reality experience intended for the building under study.
The schema depicted in Figure 1 illustrates how, starting with heterogeneous data such as historical data, other models, point clouds, and user needs, it's possible to reconstruct extended reality applications. These applications offer flexibility in terms of the accessibility levels required by the end user.
The authors define 'User needs' as those requirements that directly stem from the end users of the experience and significantly impact software development. In (Lee, 2021) the necessities for developing AR or VR applications to support non-verbal autistic users are underscored. These needs influence various aspects such as technologies, learning mechanisms, and content, but they enhance user engagement and subsequent learning. In (Anastasovitis, Georgiou, Matinopoulou, & Nikolopoulos, 2024) a holistic approach to developing applications in the realm of virtual museology is proposed. The study highlights the fundamental role of sensory enhancement, brought about using virtual reality, in promoting user inclusion through these technologies.
Among the data present in the data domain, point clouds also exist. For their effective utilization, they must undergo two distinct processes. On one hand, the point clouds are coarsely discretized for effective use within BIM modeling programs, which aids in reconstructing a reliable HBIM model that is also applicable across various domains. On the other hand, more detailed point clouds are segmented to extract only detailed objects. These objects are then used to reconstruct meshes that are subsequently used semantically in the extended reality experience.
The Semantic HBIM node explains how it's possible to define parameters within the BIM model to link more detailed meshes, or other types of data present in the museum database, to certain objects. By using data extraction in-game engine software, it's possible to split the geometry and alphanumeric content of the model and manage the data independently. This marks the beginning of a reliable BIM model that reflects the actual construction of the building.
The actual configuration of the building is undoubtedly surveyed via laser scanning of the

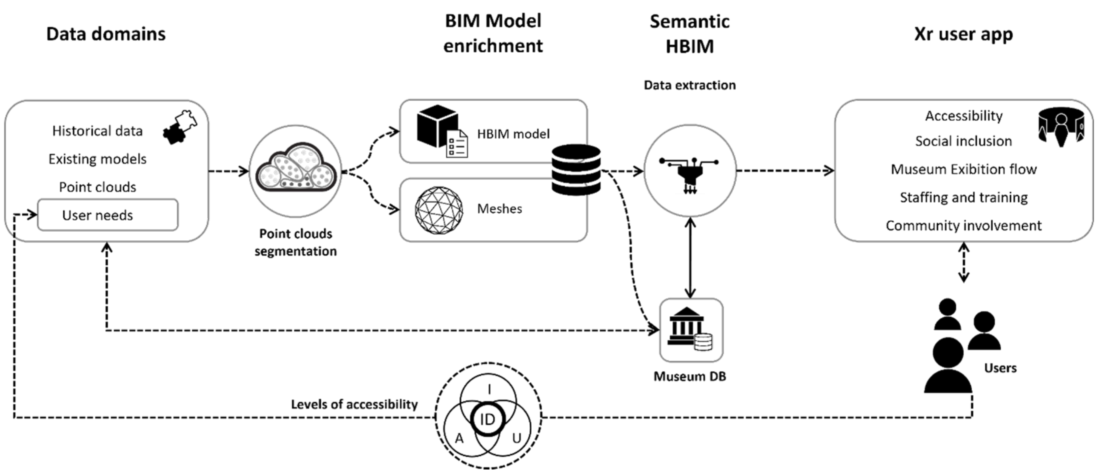

Figure 1 : Methodological schema

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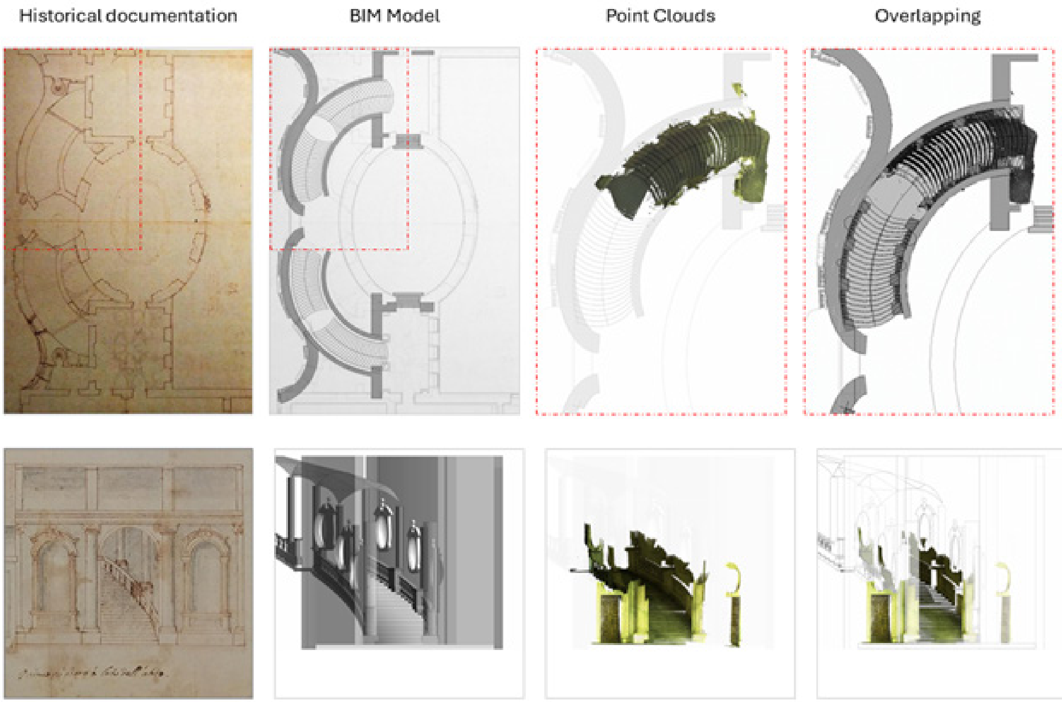

Figure 2 : Workflow for BIM modelling using point cloud

structure. This survey is conducted with more precision on certain details of the building and more approximately on the whole. This approach results in a point cloud that is usable for object placement within the BIM model with a level of detail defined later. It also allows for a more accurate reconstruction of details desired in the virtual reality application, providing greater immersion and detail in the building elements.

POINT CLOUD PROCESSING

The helical staircase of Guarino Guarini's Palazzo Carignano was selected for the case study. This case study is of particular interest because, beyond the characteristic parts that constitute the staircase, such as columns, balustrades, vaults, etc., several details make these elements unique. This aspect, related to the case study, will be discussed in greater detail later.

Starting from the left in Figure 2, the process for creating the final model of the Palazzo Carignano staircase is depicted. The HBIM modeling process commences with an analysis of various architectural documents of the artifacts, which include plans, sections, sketches, and preliminary drawings that evolve over different construction periods. Based on this documentation, (Cerri, 1990) the plan of Palazzo Carignano, particularly the entrance and elliptical staircase part, is drawn and utilized as a fundamental element for 3D digital reconstruction in Revit software. This model, combined with the knowledge gained from historical data, enabled us to identify areas of the palace that required more information for accurate description. A laser scanner survey was chosen for this task to obtain a point cloud with high geometric reliability. For that survey, F6 Handheld Scanner was adopted for the campaign. This yields a centimeter-precise point cloud that is efficient for loading into BIM modeling programs. This process enables model dimension verification, ensuring reliability in its reconstruction. Staircase elements and details are modeled with a low level of detail to avoid burdening the BIM model, facilitating rapid loading into subsequent game programs used for extended reality experiences.

Points that describe architectural components with greater detail have to be isolated to ensure their correct geometric reconstruction. The segmentation and cleaning of point clouds can be time-consuming due to the sheer volume of data resulting from the survey, namely the millions of points comprising the cloud, which are challenging to utilize without appropriate computational tools. Therefore, a mixed approach is proposed, leveraging machine learning algorithms to aid in the segmentation process and simultaneously clean the point cloud. During this process, algorithms such as RANSAC are employed to interpolate the cloud with specific shapes like planes or cylinders, and density-based clustering algorithms like DBSCAN are utilized to define homogeneous zones of points relative to specific elements. These segments are

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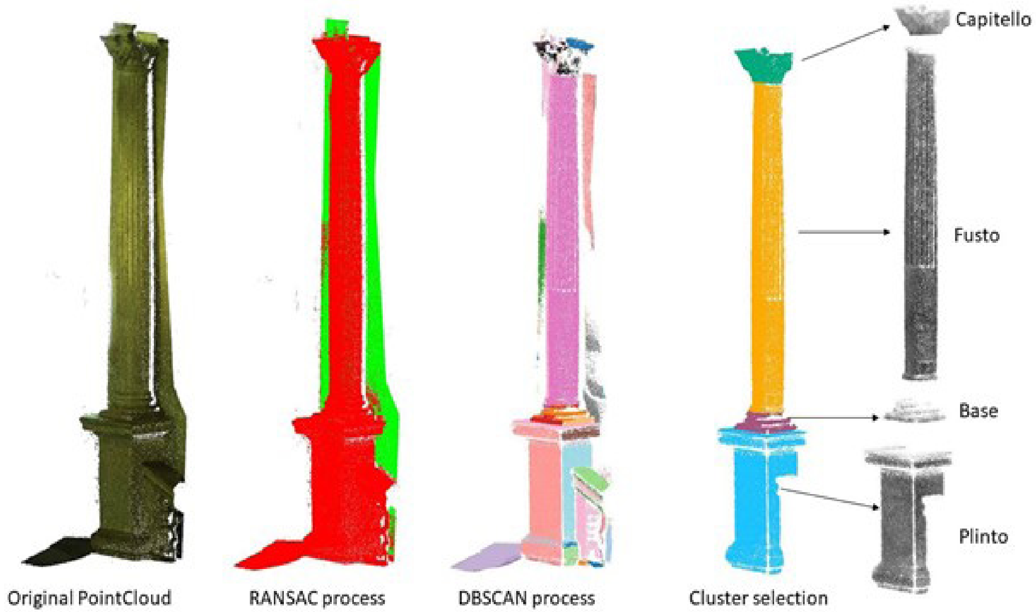

Figure 3 : Segmentation process for element selection

then used to reconstruct meshes using retopology algorithms, simplifying geometries to optimize the experience.
The figure illustrates the segmentation process applied to one of the columns of the Guariniano staircase. In this case, an initial RANSAC algorithm interpolated planes with the points in the cloud, selecting those corresponding to the staircase wall on which the columns rest. This enabled the removal of irrelevant points for column reconstruction. The column element is then defined by four distinct parts: the plinth, the base, the shaft, and the capital, facilitating accurate selection and division.
An algorithm like DBSCAN was utilized to select points describing these elements based on their spatial position and plane normal direction, allowing for the normalization and selection of homogeneous groups of points describing the four different column elements.
While this process took several minutes, it certainly required less time than manual cloud division, guaranteeing precise point selection.

MESH RECONSTRUCTION

By means of constructing different alternatives for specific elements, the point cloud data is considered as a primary source of the model and by using generative design tools, it is interpreted in regards to different polygons of 3D geometry, from high poly to low poly. Expressed simply, the study focuses on parametric retopology methodologies of classified point cloud data for generating variously detailed HBIM elements.
The modelling process of the meshes started with the collection of point cloud data. After the segmentation process, the point cloud data, which is divided in terms of different artifacts, is directly transformed into meshes by using Grasshopper Volvox component. Although remeshing the points of the cloud data is directly modelled without further iteration, it is important to emphasize the importance of the precision and integrity of point cloud plays a great role in the validity of the remeshing process. In addition, in terms of generating different LOD and LOG for semantic HBIM, the artifacts are remeshed according to different numbers of the points in the cloud data. Hence, the polymerization of the same element is variable from low to high according to the percentage of mesh faces used. The percentage of mesh faces can be controlled as a parameter for retopology of the mesh, which can result in producing different mesh types with alternative resolutions from the same point cloud.
In this process, the segmentation of point cloud plays a greater role, for producing coherent meshes. In other words, different parts of the same element are variable in terms of detail and requires different amount of mesh, segmenting and meshing elements separately provides a better solution. For instance, since the detail of the column's capital A in the image, shaft B in the image, and base C in the image is variable, the mesh faces produced in these parts also changes. Reducing the percentage of the faces of whole mesh won't give the result wanted. Thus, the segmented parts are remeshed and transformed into surfaces separately in the grasshopper as it can be seen in the figure 4.

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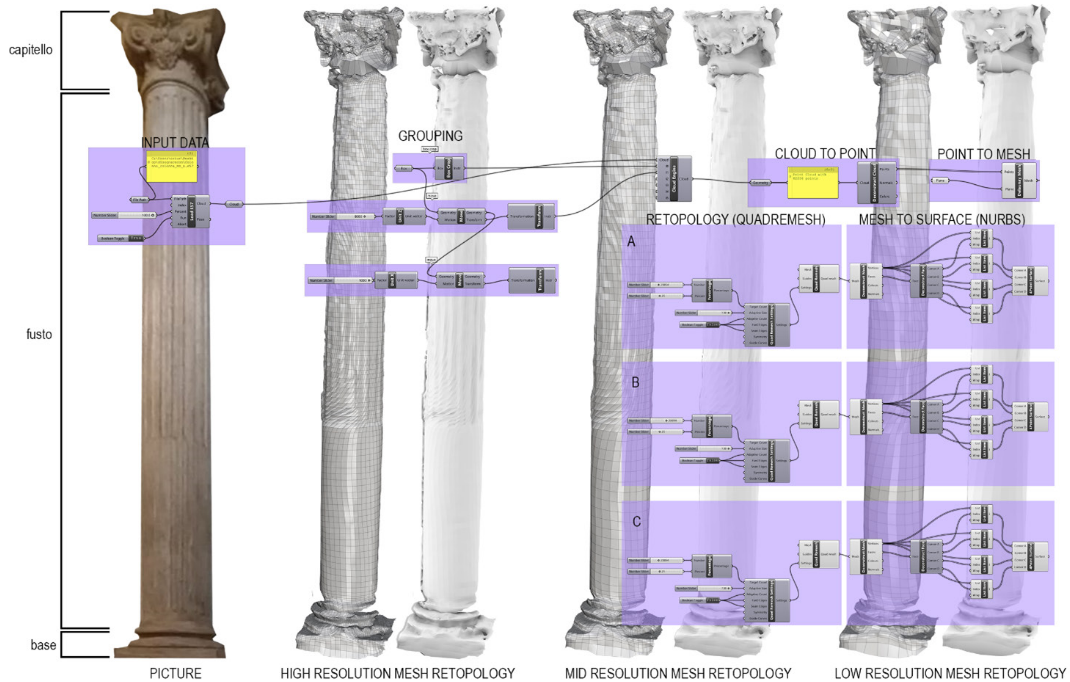

Figure 4 : Workflow for mesh reconstruction.

SEMANTIC HBIM

The BIM model is enriched with different types of data. On the one hand, the model is the simplest geometric form of the building, used for navigation, detection of objects and geometric abstraction; on the other hand, the model is semantic, i.e. populated with alphanumeric parameters that allow objects to communicate each other and with external application and database.
The HBIM model includes simple geometric shapes of architectural elements with the corresponding scale, dimensions and positions, which are not optimal for experiences in XR but lighten the CPU load of the software during the design process.
To connect the meshes at different levels of detail, it is necessary to enrich the model with a semantic code that can uniquely refer to the individual elements constituting the H-BIM model. The uniqueness of the codes ensures the ability to link data from various elements of the model to other databases containing detailed textures, more precise meshes, potential audio descriptions, and other data essential for constructing effective XR experiences.
Figure 5 illustrates the semantic enrichment strategy of the HBIM model through a simplified code structured as follows:

[Parent model]_[Element Type]_[Progressive number]

The code should be conceived as the path of subfolders leading to the identification of a file. The first part of the code pertains to the object's belonging model, and the presence of this part of the code is necessary because HBIM models are often federated models composed of various interconnected sub-models. The second part of the code identifies the type of object, such as balustrade, column niche, etc. The last element of the code uniquely identifies the object through a numerical value. As shown on the right side of Figure 5, the different elements of the model have specific characteristics stemming from the sensitivity of the constructor and designer. While excessive detail in the model's geometry can result in latency issues during its use, for storytelling purposes in XR experiences, it is crucial to be able to attribute these details to precise elements, thus correctly placing them in the virtual space.
To correctly query external databases related to the model and ensure scalability for the various XR experiences that can be conducted with the same case study, it is necessary to add another part to the code regarding the type of data being queried. The code thus becomes:

[Parent model]_[Element Type]_[Progressive number]_[Data type]

where data type indicates the type of data to be queried: mesh, audio, text, etc. This last part of the code comes directly from the game engine application because during the query, it is

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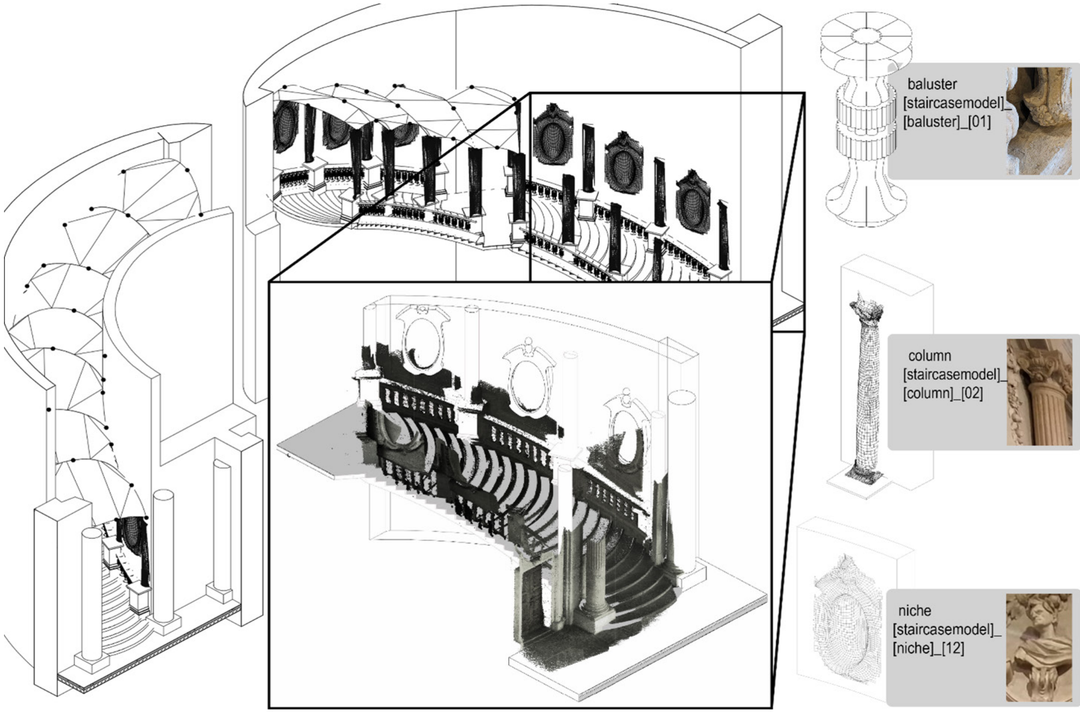

Figure 5 : BIM model Enrichment strategy.

necessary to consider not only the position where the data needs to be linked but also the needs of the users for whom the application is being developed. For example, envisioning the creation of an inclusive virtual reality application that can be used by frailty people, depending on the user's needs, it is needed to modify the content provided and therefore query different data accordingly.

RESULTS

The information contained in the HBIM model defines a semantic representation used as a filter to deliver relevant content to XR users. Figure 6 shows the proposed approach applied to the case study. Thanks to the development of the semantic H-BIM model, generating a modular XR application will be possible to fulfill user's needs. The spatial and morphological understanding of the artifact is ensured by the analysis of point clouds and the parameters of the semantic model guarantee the correct content management.
The image on the right side of Figure 6 illustrates how, through the semantic querying described in the previous chapter, it is possible to optimize the rendering of elements in the virtual model progressively. This issue is similar to the one discussed in (Chi-Kang, Bin-Shyan, & Tsong-Wuu, 2010) where the authors highlight how increasing the number of faces describing geometries also increases computational power for rendering them. By interpolating the user's position with the BIM model and the external databases associated with the museum, geometries processed with different levels of detail can be dynamically loaded using the script described in the previous chapter. The code linked to the elements in the figure shows in the data type part ML1, ML2, and ML3, indicating respectively meshes with low, medium, and high levels of detail. Through this strategy, it is possible to study the relationship between user accessibility levels in the proximity of visualised elements in the immersive experience. Levels of usability are to be carefully evaluated later in a prototype in the context of inclusive design.

CONCLUSIONS

The development of semantic HBIM prototypes for managing cultural heritage remains a challenge for the AEC industry, aiming to offer new solutions for space accessibility and inclusive data dissemination. Given the uniqueness and complexity of Italian architectural heritage, the authors propose and prefigurated a standardized approach leading to the creation of XR applications. The described approach utilizes heterogeneous data to construct an HBIM model, starting from historical data and point clouds to reconstruct a reliable model that considers the specific architectural details typical of cultural heritage. The article presents an innovative approach to expedite the process of cleaning and segmenting point clouds through machine learning, isolating the most important details, which are then translated into meshes. Through retopology techniques, these objects can be described

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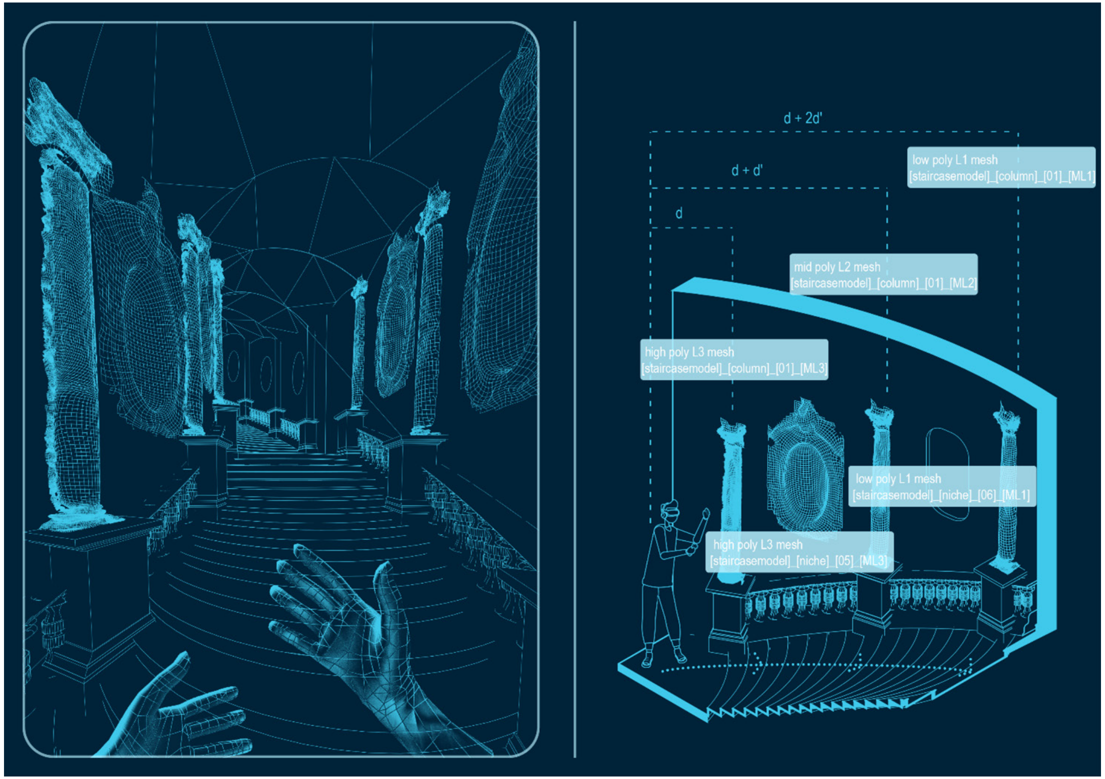

Figure 6 : Correct content management in VR application.

with progressively detailed levels of detail. The discussion also explores how semantic enrichment of BIM models can contribute to querying external databases other than the BIM one, enabling the loading of content related to specific objects in virtual reality experiences.
In conclusion, the article illustrates how the adoption of enriched HBIM models can be extremely advantageous for creating various types of applications and experiences aimed at disseminating knowledge of cultural heritage in an accessible and inclusive manner. As user needs vary, so do the types of content that can be delivered, and to reach a broad audience, museums must adapt to users' needs. [1]

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NOTES

[1] Anna Osello wrote the paragraph "Introduction", Hatice Busra Ozturk "Background", Nicola Rimella and Matteo Del Giudice "Methodology", Nicola Rimella "Point Cloud Processing", Hatice Busra Ozturk "Mesh Reconstruction", Matteo Del Giudice "Semantic HBIM" and "Results", and Nicola Rimella "Conclusion". All the authors made a contribution for the images.

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