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AN ENHANCED HBIM FRAMEWORK INTEGRATING ADVANCED TECHNOLOGIES TO STRENGTHEN THE CULTURAL HERITAGE

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SUMMARY: *Cultural heritage (CH) conveys values through every physical element and its intrinsic essence, necessitating careful attention to its preservation and longevity. In an era increasingly shaped by technology, digital conversion is an essential component of relevant research and is consistently considered for application in future CH strategies. This study addresses the unavailability of historical, graphical and technical records, in addition to the disparities in responsibilities that hinder the recognition and management of heritage in Algeria. This highlights the capability of digital exploration to initiate innovative approaches aimed at valorising heritage assets through documentation based on advanced technologies. An effective solution to represent and safeguard built heritage for professional application and dissemination via an implementation-based study that elucidates the proposed workflow across the National Theatre building in Algiers. Demonstrating that replication through a digital environment (DE) generates new ways for both physical and intangible interpretation using the digital twin (DT). Acknowledging the potential of the enhanced HBIM, this paper first describes digital surveying using 3D laser scanning. Secondly, it explores the pioneering application of artificial intelligence (AI) to process point clouds and improve semantic recognition, segmentation, and outputs. Finally, virtual reality (VR) combined with a software suite enriches the DT. The contribution to the body of knowledge lies in establishing a robust framework to investigate the relationship between AI, automated data preprocessing, and postprocessing to enhance the Scan-to-BIM process and support conservation of historical buildings. It demonstrates efficient time and resource consumption, accuracy, and overall effectiveness. The main findings include the virtual extension of existing assets by linking various representation tools throughout a comprehensive prototype, where machine learning (ML) reinforced connections between reality capture (RC), cloud processing, and ultimately BIM. Meanwhile, VR provided an immersive experience that directly impacted user engagement and stakeholder interactions, thus facilitating decision-making related to building management and enabling remote assessment.*

KEYWORDS: *Cultural Heritage, Digital Twin, Laser Scanning, 3D Point Cloud, Artificial Intelligence, Automatic Recognition, Segmentation, Virtual Reality, HBIM Workflow, Immersive Technology, Algiers National Theatre.*

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1. INTRODUCTION

Cultural heritage (CH) is a precious indicator of human history evolution. Therefore, an international framework governed by conventions has been rigorously developed to safeguard and perpetuate it by engaging states, organisations and individuals through governmental, scientific and technical efforts. Built heritage refers to historical buildings and sites that hold significant value, fostering intergenerational connections (Ren and Han, 2018) and embodying a material representation of society's collective memory, history, and beliefs (Pansoni *et al.*, 2023).

The documentation of heritage is considered to be a measure of its protection (Georgopoulos, Tapinaki and Stefanakis, 2017). 2D and 3D supports are crucial for implementing restoration and protection agendas. They also ensure managing assets effectively, influencing the selection and application of preservation techniques. Undoubtedly, a correlation is discernible between digitisation and intervening various parties in a Cultural Heritage Building Information Modelling (BIM) procedure (Nieto-Julián, Lara and Moyano, 2021), which is already transforming it into a sustainable project. Reviewing our cultural heritage from a fresh perspective is crucial. It is necessary to recreate a fragment of the past and preserve our current heritage through digital technology (Chong *et al.*, 2023). Incomplete or outdated information about heritage projects can lead to mismanagement, resulting in the loss of authenticity, time, and financial resources. This leads to the discussion of how digital exploration can initiate innovative approaches to document, represent, explain, and safeguard both tangible and intangible CH. Regarding professional use and even discovery by the public and different user categories. Compared to traditional cultural heritage documentation based essentially on archives and historical reports, such an approach is by far more efficient in conveying the past and the state of a building's integrity (Banfi, 2020). This study particularly emphasizes unlocking the potential of documentation through immersive technologies. Able to create precise digital replicas. And offer new ways to share, research, educate, and entertain (Quattrini *et al.*, 2015; Cotella, 2023; Konstantakis *et al.*, 2023) in the current digital era. It is a time when the material world is being turned into virtual reality through cyberspace reconstruction (Rushton and Schnabel, 2022).

Direct observation and surveys revealed a lack of information due to the loss of almost all archive material related to the old buildings constructed during the 19th century in Algeria. It refers to the neoclassical style of the French colonial period (Figure 1), or even to different phases of use and transformation during their temporal evolution up to the present day. In addition to the issue of synchronising the different approaches and the disparities in responsibilities. This is a challenge according to Volk, Stengel and Schultmann, 2014, who considered that existing buildings often lack documentation presenting their construction and maintenance conditions, which could affect operations and management and impede the use of BIM. These factors are capable of hindering the research agreement on a common synergy involving all the decision-makers, professional organisations and likewise local communities.

Figure 1: Historical photograph of the current National Theatre in Algiers, from Bresson square (dating back to the early 20th century). (Source: www.tna.dz).

A specific approach can be achieved by means of heritage extension through immersive technologies (Rahaman, Champion and Bekele, 2019), which are increasingly becoming a fundamental part of the CH and archaeology field. Architectural surveying is essential for understanding the physical properties and behaviour of an existing building and for recommending the required measures (Pocobelli *et al.*, 2018). Offering the specific advantage of interpreting the object from an architectural point of view (Fang *et al.*, 2022). Surveys based on Light Detection and Ranging (LIDAR) techniques have boosted the restitution and precise three-dimensional identification of heritage artefacts and spaces, becoming particularly accurate and detailed based on sophisticated sensors and increasingly improved algorithms (Buldo *et al.*, 2023). Indeed, reliable reproduction of the physical components of a detailed architectural model constitutes a milestone to initiate BIM for an existing building. In this process, a 3D digital survey based on remote capture is a crucial and initial step (Alshawabkeh, Baik and Miky, 2021).

This paper puts forward innovative tools to produce different immersive resources. To bridge the gap between the hidden architectural heritage core in contemporary cities (Figure 2) and future-focused management strategies. Moreover, it reports how digital technology has become an integral part of everyday life, and digital conversion is jointly evoked in each future strategy. This measure is key in transmitting this cultural legacy. It is a way to ensure the transfer of its values to future generations. This study presents a heritage building information modelling (HBIM) process. It demonstrates efficiency, time-saving, and precision. The literature refers to using automated and semi-automated techniques at different scales to generate outputs from data capturing to processing (Volk, Stengel and Schultmann, 2014; Pocobelli *et al.*, 2018; Fang *et al.*, 2022; Liu *et al.*, 2023). A research focus is deployed to automatically recognise and derive HBIM constructive objects from cloud data (Cotella, 2023; Roman *et al.*, 2023).

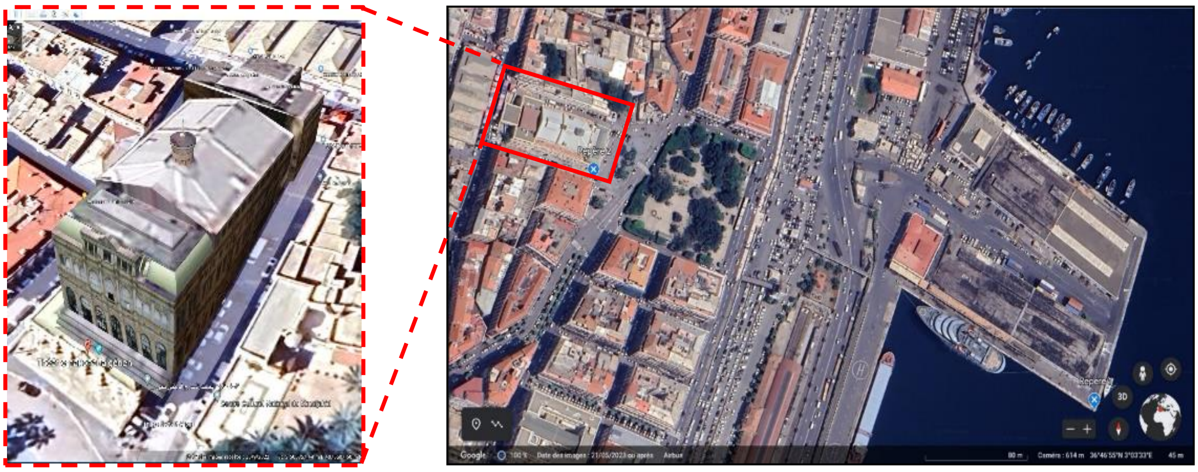


Figure 2: Satellite and street views localising the National Theatre in Algiers (Source: Google Maps & earth, 2023).

1.1 Research Aim

This study focuses on elucidating the potential role and implications of a set of virtual representations to improve the management and protection of monuments on Algeria's national list of cultural assets. An inclusive digital environment (DE) is important. It may provide a deeper historical and physical understanding of CH and foster preservation through educational initiatives and user participation.

The objective of this paper is divided into two main components: first, it explores a computational method to obtain heritage documentation and presents an attempt to facilitate and reduce time and effort required to process raw data from laser scanning to improve and facilitate data generation and digital replication. The second is about the intervention of immersive technologies to enhance the quality of the workflow using an artificial intelligence (AI) tool combined with virtual reality (VR) restitution. Enabling hence interaction between the various stakeholders involved in HBIM by adressing their specific needs. In addition to the INTRODUCTION section, the topic is structured as follows: RELATED WORK; RESEARCH METHOD and TOOLS; DATA COLLECTION and PROCESSING; RESULTS: The DIGITAL TWIN; DISCUSSION and CONCLUSION.

2. RELATED WORK

The transmission and perpetuation of CH into the future are the central focus of discourses and approaches addressing the topic (Cinieri and Zamperini, 2013; Nadkarni and Puthuvayi, 2020). The development of a 3D virtual environment (VE) should be significantly beneficial to younger generations. The use of visualisation and information dissemination tools could help to educate and implicate different public categories. While increasing awareness of CH's importance (Georgopoulos, Tapinaki and Stefanakis, 2017), appreciation and expansion of cultural tourism and community engagement (Chong *et al.*, 2023). Documenting heritage is therefore necessary to ensure its diffusion and the permanence of its attributes to preserve its values. Immersive technologies are playing a growing role, and the adoption of non-invasive techniques (Stober *et al.*, 2018; Rocha *et al.*, 2020; Di Stefano *et al.*, 2021) has been confirmed in different studies.

2.1 Applicability of BIM in Historic Field

One decade ago, BIM was already mentioned as a buzzword that has become widespread in architecture, engineering, and construction (AEC) ever since (Bregianni, 2013). It is procedural modelling. It creates 3D objects from a grammar of shapes automatically derived from an elementary vocabulary that follows production rules (Pocobelli *et al.*, 2018). It is conceived in the AEC sector as a tool based on standards to enable multidisciplinary communication between stakeholders (Graham, Chow and Fai, 2019); furthermore, it is defined as an integrated and collaborative methodology (Rocha *et al.*, 2020).

Many advantages are associated with BIM. Its facility management (Volk, Stengel and Schultmann, 2014) improves project performance and reduces risks. The method contributes to heritage preservation through its remote visualisation and collaboration functionalities, which allows an extensive and anticipated study of potential damage and interventions before the final decision is taken (Baik *et al.*, 2014; Barrile and Fotia, 2022). It also facilitates rehabilitation by digitising existing conditions (Graham, Chow and Fai, 2019), for structural analysis (Banfi, 2020), or to detect and analyse wall distortion (Fang *et al.*, 2022). Other functionalities are assigned to renovation and performance improvement, based on the estimation and analysis of energy consumption in existing buildings (Habibi, 2017); the estimates and quantities for the various design alternatives (Rocha *et al.*, 2020); and quality control (Díaz-vilariño, Lagüela and Varela, 2016). Furthermore, the BIM approach to sustainable design focuses on processing and analysing the entire life cycle (LC) of a building and provides deformation control and prediction (Volk, Stengel and Schultmann, 2014; Habibi, 2017).

From a broader perspective, BIM can be defined as a complex and valuable methodology for investigating and assessing heritage buildings (Stober *et al.*, 2018). It can also be understood as a tool to manage a large quantity of information from the graphic modelling and all the other information provided by operators involved in conservation activities (Nieto-Julián, Lara and Moyano, 2021).

2.2 Cultural Heritage Digitisation

The approach to CH through its study and management has evolved to include other disciplines. New expert profiles emerge, shedding light on this field as an interdisciplinary and intercultural (Georgopoulos, Tapinaki and Stefanakis, 2017). Subsequently, immersive technologies can foster the recognition of cultural heritage by raising attention to its values and threats (Hajirasouli *et al.*, 2021). This innovation is capable of adding economic value to cultural products and services by transforming their meaning (Münster *et al.*, 2024). Photogrammetry and terrestrial laser scanning (TLS) are now better understood, together with new technologies available for equipment and even variations in software. This has contributed to a shift from fixed stations to smartphones for producing realistic three-dimensional models (Vital and Sylaiou, 2022). The relevant literature recognises TLS as the leading technique for surveying buildings (Reinoso-Gordo *et al.*, 2018). It covers the areas of cultural heritage, archaeology, modelling and analysis of historic centres. The discussion surrounding BIM generated from a combination of laser survey data collected from TLS dates back to the last decade (Murphy, Mcgovern and Pavia, 2013; Baik *et al.*, 2014).

2.3 HBIM

The Heritage-BIM (HBIM) acronym was first introduced in 2009 by Murphy et al. (Díaz-vilariño, Lagüela and Varela, 2016). Qualified as a domain that has expanded exponentially over the last decade (Al-sakkaf *et al.*, 2020).

This concept has evolved in the CH jargon. It aims to extend a library of parametric objects, made from historical architectural data, into a comprehensive, well-integrated approach in the CH field. Generally, this process was based on data capture, followed by existing data processing, and led to digital modelling (Baik *et al.*, 2014). So, HBIM, from this view, focuses on identifying and segmenting each building element of a cultural asset (Tejedor *et al.*, 2022). It reveals additional information that the object's physical appearance conceals (Jordan-Palomar *et al.*, 2018).

The implementation of this method for various heritage interventions still emerging and developing. The research in this area is expanding with numerous studies aiming to propose and enrich a comprehensive process, where the HBIM application is perceived as a management support solution. It can also play a remedial part, ranging from restoration to structural analysis (Alshawabkeh, Baik and Miky, 2021). However, the recourse to such technology is raising many challenges. According to several studies, one of the fundamental difficulties refers to the lack of consensus on HBIM standards and classifications (Quattrini *et al.*, 2015; Dore and Murphy, 2017; Graham, Chow and Fai, 2019; Liu *et al.*, 2023; Parrinello, Sanseverino and Fu, 2023); particularly regarding LoD (level of detail or development), LoI (level of information), and LoA (level of accuracy) requirements (Volk, Stengel and Schultmann, 2014; Quattrini *et al.*, 2015; Pocobelli *et al.*, 2018; Reinoso-Gordo *et al.*, 2018; Rodríguez-Moreno *et al.*, 2018; Graham, Chow and Fai, 2019; Banfi, 2020; Rocha *et al.*, 2020; Fang *et al.*, 2022; Liu, Willkens, S. and Foreman, 2022; Cotella, 2023). In charge of assessing the quality and quantity of the input data. It represents graphical and semantic information in the model. In addition to LoG (Level of geometry) (Buldo *et al.*, 2023; Roman *et al.*, 2023). The interoperability of different BIM tools and software remains an area for discussion (Volk, Stengel and Schultmann, 2014; Habibi, 2017; Banfi, 2020; Barrile and Fotia, 2022; Tejedor *et al.*, 2022).

2.4 AI in Scan-to-BIM

Artificial intelligence (AI) research dates back to the mid-20th century, regarded as having been founded at the Dartmouth Workshop Summer Research Project on Artificial Intelligence in 1956 (Kühl *et al.*, 2022; Pavlidis, 2023). Then will be pursued by advances in knowledge across various domains spanning computer science and programming, neuroscience, robotics, and others. Despite a theoretical framework, the last decade has seen a rise in popularity and significant penetration of AI in technological innovations (Kühl *et al.*, 2022).

Widely AI covers a definition ranging from processes based on high-performance computing that empower learning from big data (Pavlidis, 2023) to the ability of the machine to perform as a human mind covering different complex reasoning functions (Kühl *et al.*, 2022). That includes machine learning (ML). Perceived by some researchers as an exclusive part of AI, covering a set of computer systems that learn to solve problems by mimicking human cognitive abilities (Kühl *et al.*, 2022). And demonstrates its interactive capacity to respond to contextual data (Özel, 2019). This concept evolves through various approaches to reshape many aspects of people’s interactions with ubiquitous technology in contemporary life (Pavlidis, 2023). Its adoption is therefore influencing the AEC. In particular, there is an increased potential and growing opportunities to revolutionise cultural heritage projects by implementing AI-based solutions (Goussous, 2020).

Along these lines, AI is a game changer (Münster *et al.*, 2024). Able to replicate tasks that require human intelligence to empower management and different preservation actions. In the context of cultural heritage, technological prospects have been embraced for research paths, projects and apps. Spread across image analysis; aided digitisation and virtual restoration; object recognition and classification; immersive experiences; damage analysis and interpretation; predictive modelling; historical transcription; detection and security; and tourism personalisation (Goussous, 2020; Akyol and Avcı, 2023; Pavlidis, 2023; Münster *et al.*, 2024). To efficiently preserve the built environment, artworks and archaeological objects.

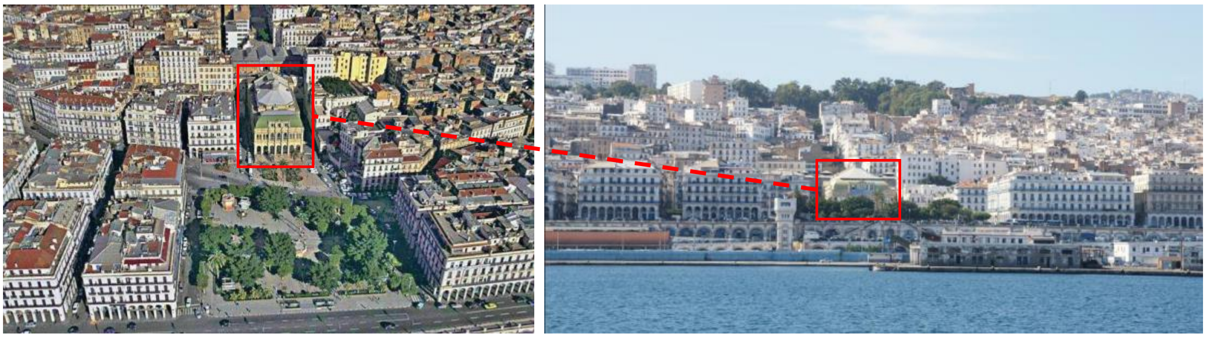
Henceforth, 3D digitisation and AI applications are recognised as foundational pillars that will underpin the future of archaeology and cultural heritage (Pavlidis, 2023). Research has shifted to solutions for fully automated point cloud processing with a target to accelerate this step in the future. Which is expected to enable the recognition of construction elements by identifying objects’ characteristics and shape/typology extraction (Díaz-vilariño, Lagüela and Varela, 2016; Dore and Murphy, 2017). intelligent detection is recommended based on the chromatic properties extracted from the point cloud (Alshawabkeh, Baik and Miky, 2021).

HBIM focuses on rapid and automated solutions including the potential to automate the Scan-to-BIM process through ML that facilitates the semantic segmentation of point cloud data (Croce, 2022). Thus, the segmentation of 2D and 3D data becomes possible owing to trained subsets (Buldo *et al.*, 2023; Pansoni *et al.*, 2023). This covers the aspects of an artificial neural network (ANN), a method in which the computer independently executes a flexible mathematical model (Tejedor *et al.*, 2022). As a result, exploiting AI to find, segment, and categorise the physical properties of a digitised architectural heritage space based on point clouds, forms the main initiator of geometric reconstruction (Cotella, 2023), despite its complexity caused by its irregularity.

3. RESEARCH METHOD AND TOOLS

The investigation method adopted in this study draws on the digitisation of existing buildings. Laser scanning, particularly TLS, has emerged in the last decade as an indispensable tool for acquiring accurate documentation data by capturing and depicting complex geometries of architectural and structural shapes. That leads to the precise data needed for HBIM modelling (Banfi, 2020; Liu *et al.*, 2023). The collected data and information are refined and ultimately transformed into diverse outputs, by several multi-disciplinary stakeholders involved in the process. This refers to the Scan-to-BIM method, which can detect all components with details of historic buildings, ruins, or archaeological sites and then represent them in terms of their morphological and typological specificity (Banfi, 2020). The method is looking ahead to automated workflow (Buldo *et al.*, 2023), where digitisation operations enable As-Built data to be recovered and the condition of the existing building use and possible deformation to be monitored related to its lifecycle stages (Díaz-vilariño, Lagüela and Varela, 2016). This technique has been presented in several papers and offers the possibility of obtaining an HBIM model through restitution based on the geometry characteristics extracted from the point cloud (Banfi, 2020; Alshawabkeh, Baik and Miky, 2021). Scan-to-BIM identified by reality capturing (RC) could be an integrated approach that is range-based using TLS and image-based using photogrammetry (Antuono *et al.*, 2023). Generally, it involves four successive steps: point cloud acquisition, segmentation, classification, and model reconstruction (Roman *et al.*, 2023).

The geographical context of this study is Algiers, a metropolis on the southern shore of the Mediterranean Sea with a varied urban fabric, as demonstrated by this part of the city in Figure 3-A. The historical fragments of the traditional Kasbah stand side by side with neighbourhoods that have developed and coexisted for centuries, right up to the present day. This led to various protection measures applicable by different authorities, statuses, and actions. These were dispatched between local authorities and the Ministry of Culture's hierarchical services.



A **B**

Figure 3: Mahieddine Bachtarzi Theatre in the historic fabric of Algiers. A- Aerial view of the theatre and Port Said Square (available at https://youtu.be/mX19cveOKgQ). B- landscape of Algiers from the Mediterranean taken by Yves Jalabert in 2009 (available at https://www.flickr.com/photos/yves_jalabert/5076007310/in/album-72157625026884397/).

Figure 4 illustrates the Algerian National Theatre *Mahieddine Bachtarzi* (TNA), identified as the case study to conduct the survey. A neoclassical building of the 19th century (*Catalogue of TNA Spaces*, 2019), inherited from the French colonial era in Algeria, serving lucrative, social, cultural and entertainment functions, and making the most of its visible influence through the activities and events organised and hosted on local, national and even international scales.

A B C D E

Figure 4: External photographs presenting the National Theatre Mahieddine Bachtarzi in Algiers. (Source: Author, 2022). A- South façade on the alley Abderrahmane Nait Merzouk; B- Main façade on Abane Ramdane Street and Port Said Square; C- North façade facing Mohamed Touri Street; D & E - Views of the west façade on commander Djouadi Street.

Despite the fact that public interest in the national theatre building itself remains problematic in terms of its socio-political acceptance in relation to its colonial identity. TNA is a historical monument classified on the national list of protected cultural properties (*General List of Protected Cultural Property in Algeria*, 2019), and located in a central dense urban area. Within the perimeter of the city's classified historic mixed area, thus protected in the safeguarded sector of Algiers instituted and administered by the National Agency for Safeguarded Sectors (ANSS) (*Permanent Safeguarding Plan*, 2022). The theatre building is adjacent to the Kasbah World Heritage site boundary (*Delimitation of the Kasbah of Algiers- UNESCO*, 2013) and is an important marker of Algiers's urban image as presented in Figure 3-B.

The HBIM process faces some constraints. These are due to the heritage building's unique morphology, non-standard components and inherent details (Alshawabkeh, Baik and Miky, 2021). The literature highlighted the role of advanced technologies and made known multiple innovative instruments used for on-site surveys and heritage field information collection. Including photogrammetry, aerial photogrammetry, terrestrial laser scanning, mobile laser scanning, and 360-degree virtual tours (Baik *et al.*, 2014; Pocobelli *et al.*, 2018; Al-Sakkaf and Ahmed, 2019; Rocha *et al.*, 2020; Alshawabkeh, Baik and Miky, 2021; Di Stefano *et al.*, 2021; Liu, Willkens, S. and Foreman, 2022; Tejedor *et al.*, 2022; Antuono *et al.*, 2023). In addition to the 3D software for streamlining and enhancing the accuracy during the RC phases. Subsequently, a terrestrial laser scanner was employed as the appropriate equipment for TNA building recording (Figure 5). The choice aimed to improve spatial data collection in such a complex building. It would enable precise geometric reproductions of detailed 3D objects and indoor spaces in less time.

Figure 5: Reality capture, FARO FocusS350 adjustment during the recording of interior spaces of the main auditorium in Mahieddine Bachtarzi Theatre. (Source: Author, 2022).

3.1 TNA As-Is

Preserving CH requires specific ethical and technical considerations. An As-Is BIM refers to a virtual registration of the real current condition of the historical buildings. They have been subject to transformation or deterioration, renovation, extension or refurbishment during or after their design and construction throughout their life and use (Tang *et al.*, 2010; Croce *et al.*, 2023). Based on its regular maintenance, exhaustive As-Is documentation remains necessary to plan and target specific actions on the building (Díaz-vilariño, Lagüela and Varela, 2016). Furthermore, Díaz-vilariño, Lagüela and Varela, 2016 and Vital and Sylaiou, 2022 argued that As-Built BIM for historical buildings is founded on representing a recording of an existing state after construction. In a complementary role, it involves an accurate representation of a building's current condition through As-Is recording. Fusing these two stages provides the possibility of using original historical and architectural data to represent the building's geometry. Then, generate a parametric object library. It should be inserted directly onto RC-collected data from point clouds or large image surveys (Wang, Cho and Kim, 2015; Díaz-vilariño, Lagüela and Varela, 2016). This would provide reliable documentation and a management tool for a range of activities.

The study centred on creating the TNA As-Is model. An aspect that is a comprehensive, accurate and detailed representation of the building's current state. It should allow for an assessment of its architecture. This includes its materials, textures, general condition and state of decay. It must stress the need for precise measurements in capturing reality. As-Is plays a fundamental role, enabling architects and conservators to work on an updated realistic version of the building. And to make informed choices and strategic interventions while maintaining the historical and aesthetic authenticity of the property. We summarise the process steps as follows: *Preliminary Documentation*, based on historical information collection, aims to understand the ancient building. It uses architectural drawings, technical and administrative reports, and photographs. *Data* collection involves recording detailed data on a real building. This includes its style, condition, geometry, materials, and damage. As a result, the data flow is extensive (Vital and Sylaiou, 2022) and heterogeneous. It needs organisation and classification for further use, comprising technical, management, and research purposes. *Digital modelling* creates complete digital 2D supports, 3D models, or BIM.

3.2 Implementation of the HBIM method

Considering that, the applicability of BIM to CH buildings requires merging technical information (such as geometry and volumes, structural components, used materials, construction techniques and state of conservation). In addition to historical information (considered as non-geometric data such as archives, maintenance reports, condition surveys, and archaeological research), a central database with an overview of the building is created (Reinoso-Gordo *et al.*, 2018; Liu, Willkens, S. and Foreman, 2022; Tejedor *et al.*, 2022). It also offers a consultation facility for each evolution phase (Rodríguez-Moreno et al., 2018). In addition, it provides materials to support research and assessment of the historical environment.

The HBIM model was developed as a virtual sample of the historical building that already exists, in whole or in part. It is Therefore a database containing a range of information that can be consulted according to the needs of the various actors involved (Liu, Willkens, S. and Foreman, 2022). This database can simultaneously support project teams. It can also integrate As-built information from old documents. Besides, regular visual inspections and control equipment make it possible to monitor and maintain the buildings during their LC through regular visual inspections and control equipment (Rodrigues *et al.*, 2019).

4. DATA COLLECTION AND PROCESSING

4.1 TNA-HBIM Framework

As the HBIM is a complex process, its implementation for the current study has been realised through the following successive phases:

4.1.1 Exploration of the Studied Building

The available resources regarding the original state of the *Mahieddine Bachtarzi* theatre were subject to an interpretation of the historiographic, artistic and urban context. This resulted in a primary diagnosis to align the archive material. It is important to note that the original documentation related to the design and construction of the theatre during the 19th century has been lost, along with the absence of technical documents for its management throughout the 20th century. An observation, supported by multicriteria and multiscale surveys conducted with stakeholders involved in building management, revealed that, to this day, no reliable technical or graphical data is available.

The on-site exploration made it possible to plan the position and settings of the capture stations. In relation to the layout of the spaces and the direct/indirect relationships linking the various entities to have physical reference points to be coordinated when digitising.

4.1.2 Employed Equipment

TLS or laser scanners have been described (Dore and Murphy, 2017) as one of the most efficient data collection methods for accurate As-Built modelling. It operates under four principles: triangulation, time of flight, phase comparison and angle measurement. At the same time, TLS has been suggested as a suitable method for recovering the As-Built of building including a considerable degree of detail (Rodríguez-Moreno *et al.*, 2018).

Its functioning principle (Riveiro *et al.*, 2016) is founded on distance calculation between the equipment and the target object through a laser beam, emitting to a mirror rotating mechanism on a prism for 360° measurement capture, on both vertical and horizontal axes. Taking into account a deflection angle to provide the coordinates of millions of three-dimensional points in a spherical system by assembling the points reflected by all objects surrounding the scanner (Tejedor *et al.*, 2022). Repeating this operation over the entire field of view at a high speed produces the relative positions of the points. And generates a condensed 3D environment that is presented as a Cloud of Points or Dots.

A static laser scanner FARO FocusS350 (*FARO ® Focus Laser Scanner*, 2021) was used for the present on-site study and its characteristics are summarised in Table 1-Appendix A.

4.1.3 Recording

On-site data collection is known as recording the existing building. It demands manual work to select and install the scanner and markers in the appropriate locations, as shown in Figure 6. The capturing process at each location takes time depending on the feature's details and required level of detail (LoD). The number of stations depends on the spatial size as well as its formal irregularities, which necessitate multiplying the visual angles.

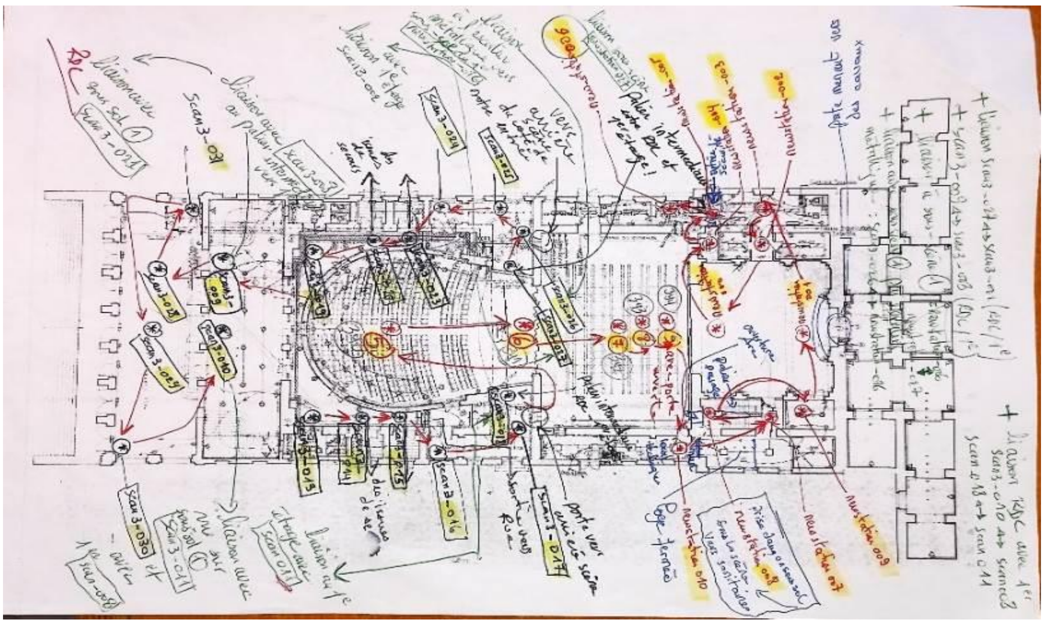


Figure 6: Example of capture stations pathway on the ground floor of the Theatre. (Source: Author, 2022).

Because the laser scanner captures the geometric details of the surface included in the field of incidence, determined by its radius and range distance, it provides a dense and reliable 3D point cloud (Alshawabkeh, Baik and Miky, 2021). In addition to quantitative spatial data, other values related to spectral properties, such as RGB data (Riveiro *et al.*, 2016; Stober *et al.*, 2018; Liu, Willkens, S. and Foreman, 2022), intensity value, and temperature information (Fang *et al.*, 2022), are identified with geometric coordinates (X, Y, Z) for each single captured point in a digital environment (DE). This enables Massive Data Capture (MDC) (Nieto-Julián, Lara and Moyano, 2021), which can be used to identify As-Is and verify their accuracy and similarity with the original morphological characteristics of the monument.

4.1.4 Data Collection and Pre-Processing

To stress the importance of including TLS technology in the development of HBIM work, and demonstrate its significant impact on enhancing the accuracy and reliability of the workflow (Liu et al., 2023), static laser scanning was used to capture the property's state and to update the architectural survey. It allows obtaining a 3D representation decomposed into surfaces known as a geometric automated method using LIDAR technology. It has the advantage of simultaneously capturing spatial 3D point clouds and panoramic photographs, but still requires preprocessing steps to generate outputs that can be used to create Computer-Aided Design (CAD) and BIM. Usually, the registration stage involves referencing, combining, and linking individual scans. It requires identifying targets or common points in the scans, segmenting the point clouds and filtering out undesired data (Dore and Murphy, 2017), or removing scanning data noise (Stober *et al.*, 2018).

4.2 TNA Initial 3D Reconstruction

As detailed in the previous paragraphs, the creation of a TNA 3D model simultaneously includes physical survey, reality capture, data analysis, modelling, and monitoring (Liu, Willkens, S. and Foreman, 2022). Therefore, raw scans recorded in situ required a sequence of operations to implement the primitive 3D feature. Starting with indexing of all the scan files (*.fls*) required to display the component, as shown in Figure 7-A.

The second step merges multiple viewpoint scans in a common referential frame to obtain an entire 3D scene. The position of each scan must be defined in relation to the position of others as indicated in Figure 7-B.

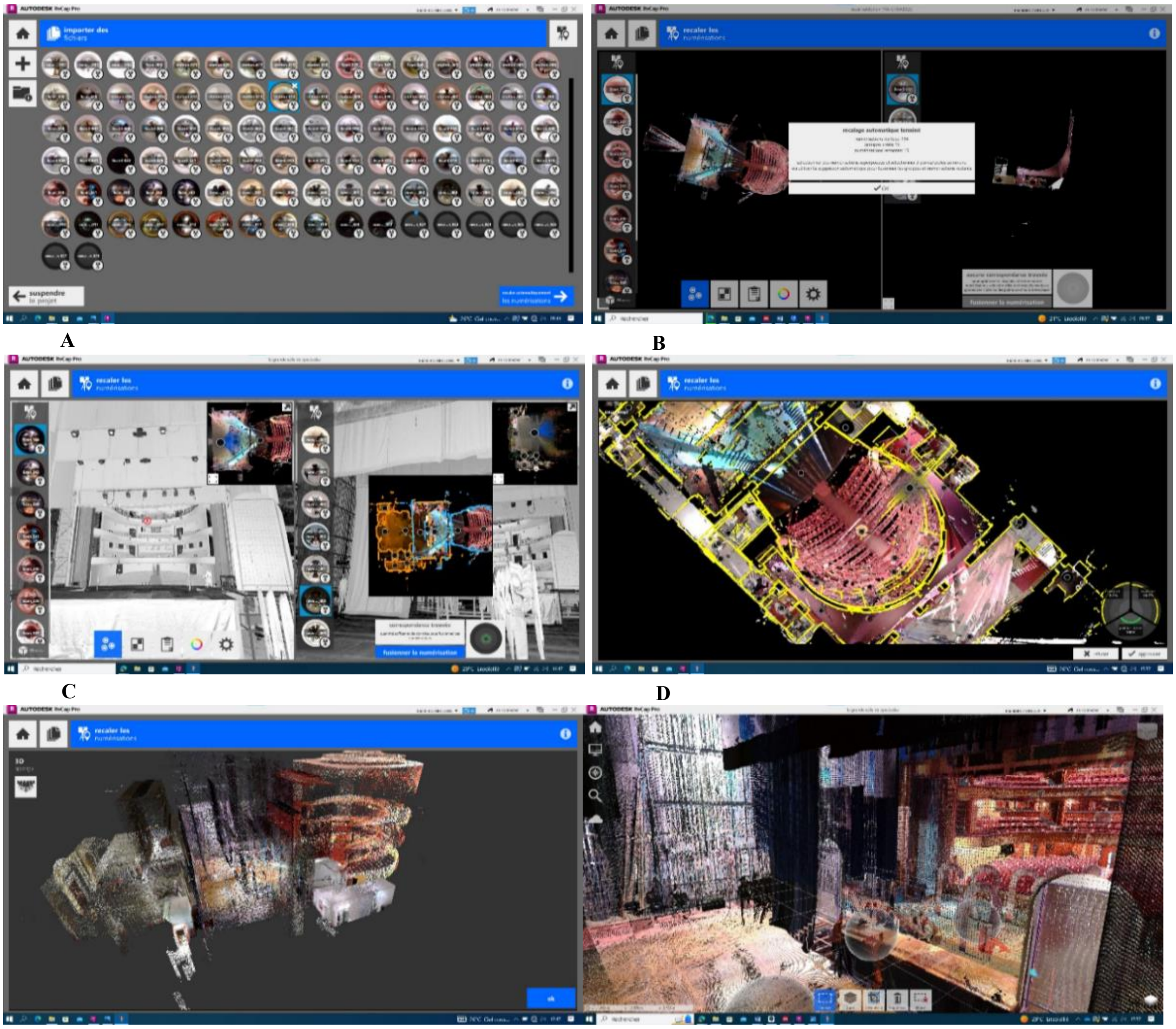
A semi-automatic alignment was carried out using RECap-pro© (v 23.1, Autodesk). Due to the size of *Mahieddine Bachtarzi* Theatre and its complex spatial configuration, as well as the resolution and obstructions encountered by the laser beam when recording, 114 captured stations were integrated for indoor scenes. This required manual re-alignment to assist the creation of specific component correlations as explained in Figures.7-C & 7-D. That was possible using a geometric triangulation system, and by identifying targets, and segments that served as tie points.

Figures.7-E & 7-F explain the third step concerning improving and cleaning up point cloud data, recording noise and irrelevant content. Saving then the project, and exporting the files needed for the next stages of the documentation (i.e., both *.rcp* and *.e57*).

4.3 The Use of AI

The ANN was trained to simulate the human interpretation of the data models (Cacciari and Pocobelli, 2022). Opening up a specific field in which a computer transposes experimental data into its trained model, resulting in an AI algorithm. This method is emerging in the literature investigating automatic algorithms to transform 3D point clouds into independent geometric components. The focus is put on classifying the extracted information from captured data (Barrile and Fotia, 2022; Buldo *et al.*, 2023) by segmenting point clouds into regions and categorising these points according to similar properties. A reference study (Croce *et al.*, 2023) explored an AI-based classification method for automating Scan-to-BIM using semantic segmentation, referring to prior knowledge of 2D and 3D architectural scenes.

Figure 8 explains how the used AI in this study complements and enriches the Scan-to-BIM method by reinforcing the links between the various successive stages (preprocessing of raw data- identification-segmentation- classification- CAD model) and extensive parallel stages (parametric modelling- VR). The intervention of the trained algorithm on the input scan data resulted in semantically classified and annotated files. It generates exportable output composed of interactive layers and objects into the CAD software. That could be directly and precisely employed to automate the model's processing for BIM using an integrated plug-in. A semantic annotation presented on a 3D reference frame of all recognised architectural components relies on a predictive ML-checked model (Croce, 2022). This step forms the basis for reconstructing the HBIM model using the same logic, order and organisation as the 3D modelling software. Next, representation is enriched by additional local data. This includes both metric and non-metric information. Each constructive element is associated with geometric, material mapping, and descriptive attributes depicting their state of conservation or deterioration. This interoperability offers the CH a new tool for validation and assistance. It can make autonomous decisions, supervised by the developer.



A B C D E F

Figure 7: TNA-Project Lasergrammetry preprocessing steps. (Source: Author, 2022). A- Registration of scans in the project; B- Automatic alignment processing & creation of groups; C- Manual matching of components using 3D view and floor comparison (to refer to blue & orange outlines); D-Recalibration settings verification; E- Data point acquisition and visualisation in 3D space; F- cleaning & optimisation of the point cloud.

4.3.1 Assisted Post-Processing

The BIM model of TNA (*.rvt & .rfa*) was created with Revit© (v 2023, Autodesk) using imported files. Aurivus AI algorithm converted them from condensed point clouds and processed them using Aurivus add-in (v2.2.1, AURIVUS). It was therefore possible to categorise and then materialise the components. Figure 9 clarifies a part of the pre-modelled point cloud that generated an interactive CAD model by identifying each architectural component and object included in the surveyed space. It also shows the superimposition of layers during the recognition process of selected parts like the main auditorium, perfrormance stage, backstage, and their auxiliary spaces. The trained ML identified and organised automatically using chromatic and geometric properties all physical components. This classification was achieved through classes using a colour scheme following the example of : grey for walls, purple for floors, green for doors, and red for staircases.

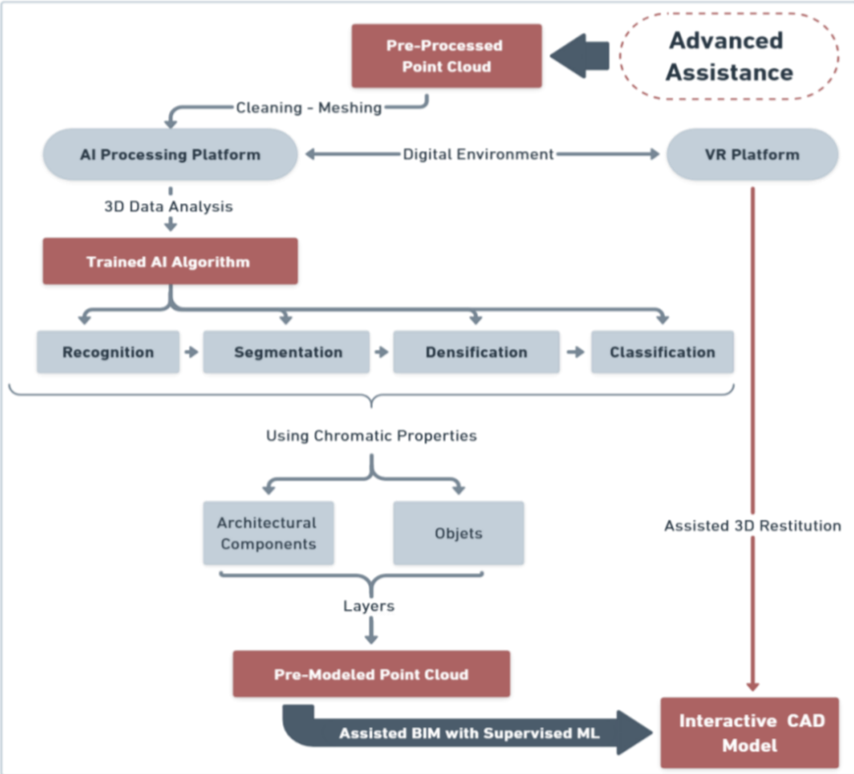


Figure 8: Steps to summarise AI intervention in the experienced advanced HBIM. (Source: Author, 2023).

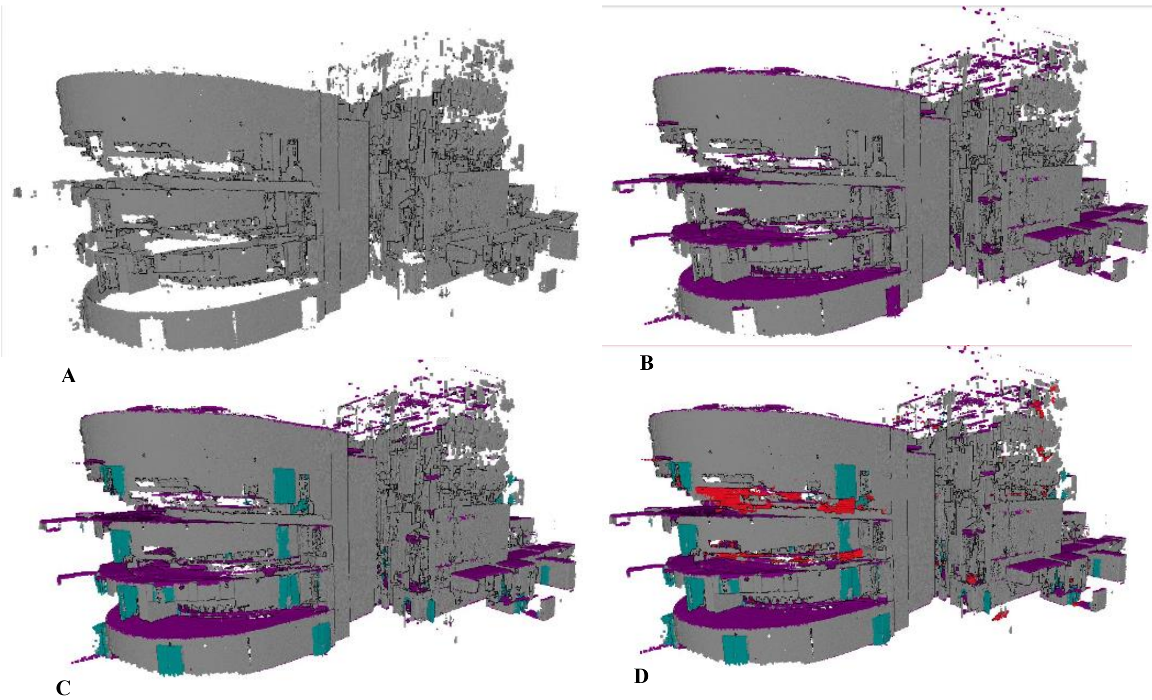


Figure 9: Example of gradual identification of the Mustafa Kateb Auditorium elements by the AI-Aurivus Algorithm according to their classes. (Source: Author, 2023). A- Walls (grey); B- Walls & Floors (grey+purple); C- Walls, Floors & Doors (grey+purple+green); D- Walls, Floors, Doors & Stairs (grey+purple+green+red).

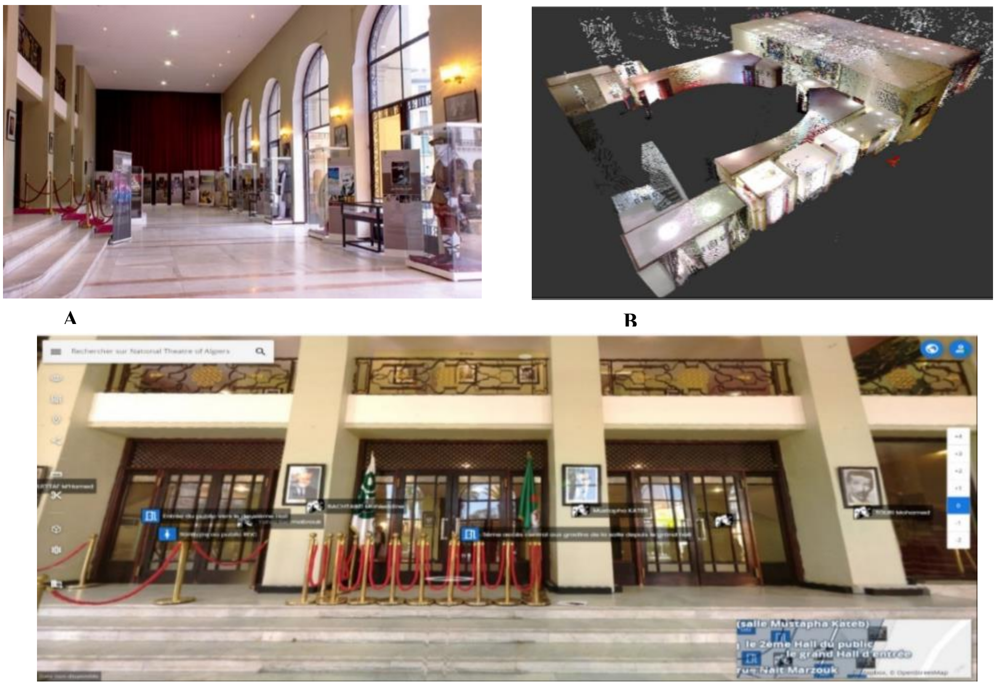
4.4 Integrating VR Restitution

Among the advantages described above offered by the HBIM model is the potential to foster CH using virtual reality. Whether by creating specific applications or sharing virtual models on the web (Barrile and Fotia, 2022). The application of VR extends the capacity of CH, but transforming heritage sites into accessible digital support is still a major challenge today. However centred on technology evolution, VR implementation based on cross-platform experiences allows improved use of outputs from 3D reconstruction (Pervolarakis *et al.*, 2023). It contributes to bringing it closer to users and attracting their attention with new functionalities that can convey historical information differently (Chong *et al.*, 2023). Perceived as an important support tool for experts (Pavlidis, 2023), it also encourages public participation through historical and cultural dissemination projects supported by active and passive virtual reality (Graham, Chow and Fai, 2019). Over the last decade, the use of immersive technologies to digitally document CH and prevent its deterioration through VR presentations has increased (Hajirasouli *et al.*, 2021). It has become a driving factor in the sector (Bianconi *et al.*, 2023).

Considering that one of the objectives of this work was to ensure interaction between the different actors and through the various stages of HBIM processing, the VR restitution provided us with multimodal support initiated by the 3D reconstruction. The heritage property and its attributes are synthesised through a realistic representation in a VE that overcomes the tangible aspect (Pervolarakis *et al.*, 2023). Consequently, we chose to focus our analysis on a Web-based VR experience (Stanga, Banfi and Roascio, 2023) enabling content to be updated in real-time, whereby the developer creates, modifies and shares content seamlessly and without the need for permission, updating or downloading by the users. As well as being versatile, the Web-VR platform supports a broad spectrum of devices, enabling optimised and adapted accessibility to adress the needs of a wider public.

For practical purposes, the TNA building was divided into two main components: the `Public Reception Hall` (Figure 10). And the main theatre auditorium called *`Mustapha Kateb`* (Figure 11), with a capacity of 700 seats (*Catalogue of TNA Spaces*, 2019) devided between the orchestra and three balcony levels.

By combining spatial data in a VE with historical data, we obtained a cross-section of information linked from the building's past to its current condition, which will be elaborated upon in the RESULTS section.



A B C

Figure 10: From real to virtual restitution of the main reception hall, the public corridors and technical annexes. A- Real photography; B- 3D visualisation of components using RECap-pro©; C- Space exploration and discovery using VR plateform. (Source: Author, 2023).

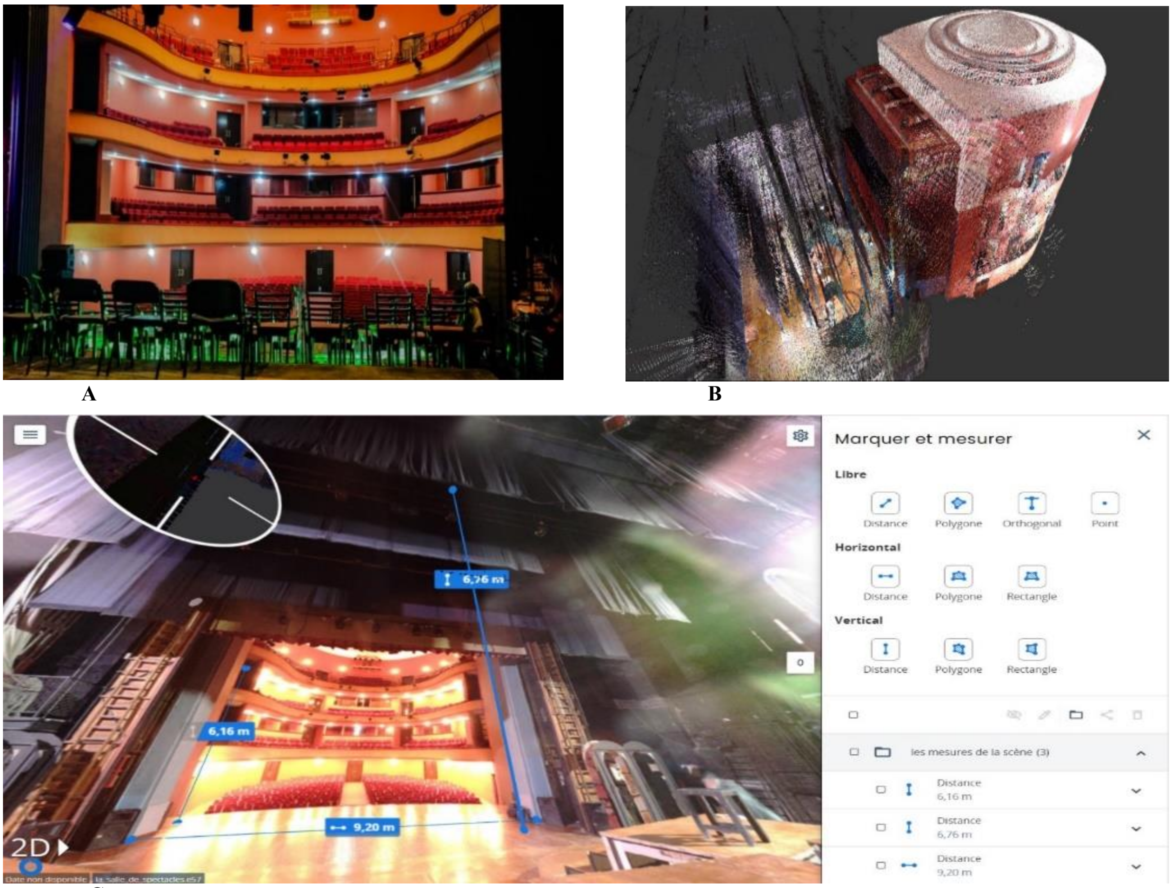


Figure 11: From real to virtual restitution of the Mustapha Kateb Auditorium. A- Real photography from the stage; B- 3D visualisation of components using RECap-pro©; C- The stage area exploration and monitoring using VR plateform. (Source: Author, 2023).

5. RESULTS: THE DIGITAL TWIN

The outcome of implementing the computational approach outlined above in the case study gave rise to the digital twin, which pertains to the representation of physical objects via virtual modes using innovative technological tools (Konstantakis *et al.*, 2023).

A digital twin of a historic building allows the virtual extension of existing assets, creating a digital cultural heritage (DCH) (Hajirasouli *et al.*, 2021; Pervolarakis *et al.*, 2023). Furthermore, this digital version of the building represents an accurate and updated model turned into an electronic form. And demonstrates its ability to preserve the heritage building values by conserving its prototype under a realistic state as a historical connector. This is usually considered to detect needs for care or maintenance at any point of the building's subsequent LC stages (Al-Sakkaf and Ahmed, 2019).

In this section, we design a framework to assist the new recognition of CH using the digital documentation of an existing building. It serves to generate 2D architectural supports, 3D architectural and graphic visualisation, and a BIM database. Combining various tools to create an immersive VR environment and proposing a model for a digital twin implementation for the TNA.

5.1 Enhanced TNA-HBIM Process

Although the potential of BIM is recognised in the field of construction, from design and management to completion. Its implementation for existing buildings is a design process in the opposite direction (Murphy, Mcgovern and Pavia, 2013) and takes the meaning of reverse engineering (Riveiro *et al.*, 2016; Parrinello, Sanseverino and Fu, 2023). Therefore, HBIM could be understood as a two-way iterative process evolving bi-directionally. By turning historical objects or structures into digital supports, they reveal information about their original design and construction. The HBIM concept encompasses the preservation of the information, attributes, and relationships inherent to the heritage asset (Rodríguez-Moreno *et al.*, 2018). As a result, the information stored through the HBIM model is preserved in a common database, which can be augmented and used in the subsequent planning and execution of operations at different times (Barrile and Fotia, 2022).

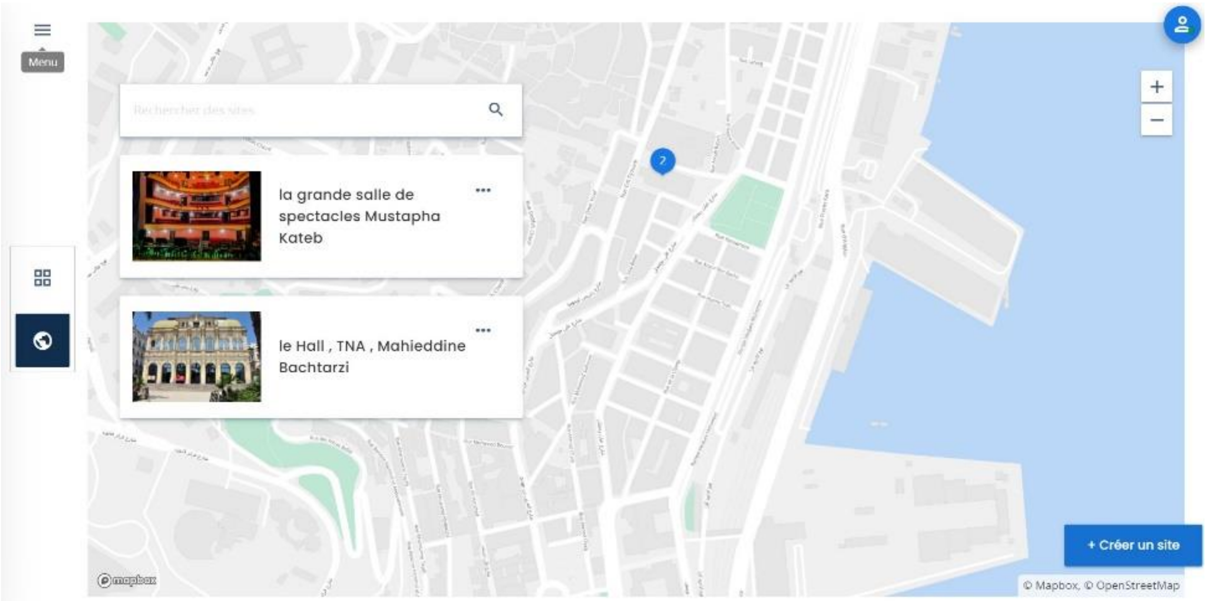


Figure 12: The georeferenced projects related to TNA on NavVis IVION CORE Platform. (Source: Author, 2023).

The steps of the HBIM method are explained in the Data Collection and Processing section. Here, we emphasize that the results are organised toward a TNA-Digital Twin. The digital recording process was preceded by a physical exploration of the site, supported by both retrospective and current management information, gathered from previous reports and interviews with the present staff. This guided us to identify the gaps and to organise the on-site investigation, as explained in the Recording, Data Collection, and Pre-Processing paragraphs. After the captured scans were indexed and combined, the resulting point clouds were cleaned to keep only the important components considered for this study and were parameterised to obtain the appropriate cloud format and size. AI assisted in filtering all points in the cloud, segmenting, and automatically recognising and categorising the physical components of the space, whether structural, furniture, or equipment. The project's technical, formal, and spatial aspects were displayed using the VR Platform. While this tool was simultaneously deployed for project implantation on its precise georeferenced location (Figure 12). The NavVis IVION platform's engines enabled the generation of a complete model. Providing access to a realistic display using a panoramic data package derived from on-site records and/or by merging them with enhanced point clouds, which became configurable.

All these steps and their interactions are summarised in Figure 13 illustrating the enhanced Scan-to-BIM framework. It synthesises the links between the digital recording and the HBIM. Building components were modelled based on BIM software, and non-geometric information from descriptions, historiography, and photographs was added. As a result, precise data can be optimised using plug-ins for the two platforms, the AI (Aurivus) and the VR (NavVis IVION) integrated into the Revit© software.

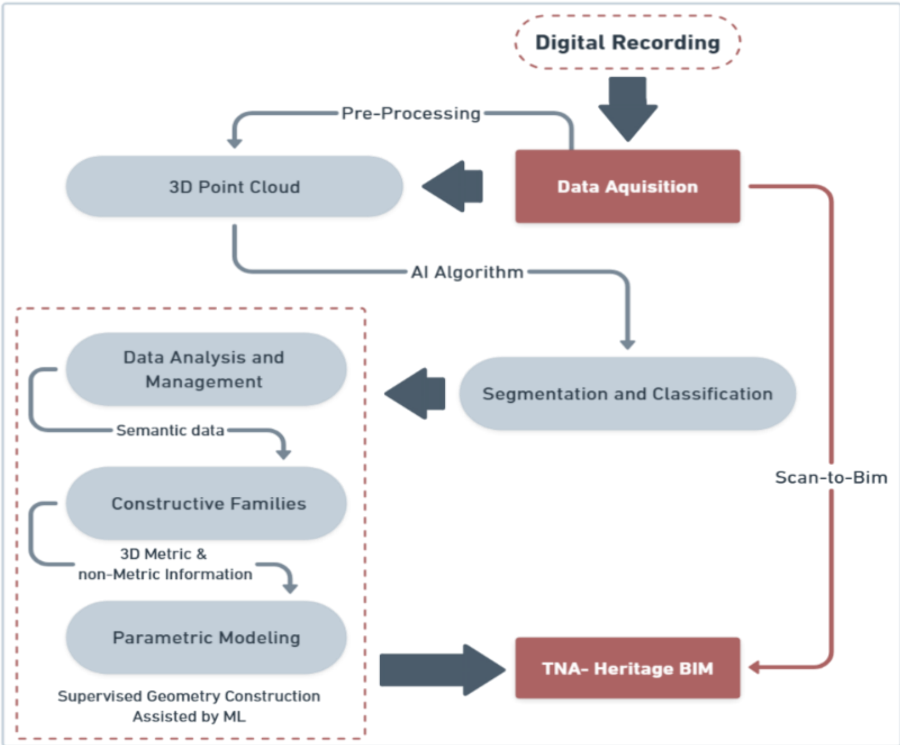


Figure 13: AI- and VR- Enhanced Scan-to-BIM framework. (Source: Author, 2023).

The AI plug-in extends and synchronises the modelling linked to the cloud processed through the AI (Aurivus) platform. Saving time and simplifying the generation of the parametric library. In addition, the VR plug-in connected the modelling software to the VR (NavVis IVION) platform and enabled a realistic view of space directly from the BIM-3D model. Allowing the integration of supplementary non-geometric data sources.

The interaction between the initial state of the TNA historic building and its current As-Is condition, recorded through lasergrammetry, provides valuable insights. We were able to retrace the path of the building's conservation condition and development as well as to recover the know-how and expertise related to some LC phases. Across a precise digital twin, it was possible to approach how the building should be promoted in the future.

5.1.1 TNA 3D Modelling

The modelling step starts with the creation of constructive elements by assigning their parameters in advance (Figure 14-A). Next, they are constructed using basic geometry, surface meshing, and texture mapping (Pocobelli *et al.*, 2018). The semantic families of these elements are then organised in a specific parametric library. Constructive families, including structural elements (load-bearing walls and columns), floors, partitions, stairs, roofs, and openings (doors and windows), have been created using Revit©. All these elements can be identified by subcategories in the HBIM model. They are recognised not only using geometric representation but also by the attributes of materials and the specific constitution of each item (Figure 14-C).

It was found that abstract computer representation provides each physical world element with a digital twin that is interconnected with other elements and sub-elements (Rodríguez-Moreno *et al.*, 2018; Liu, Willkens, S. and Foreman, 2022). While allowing multi-scale interrelations, the HBIM model articulates the project with its implantation context, the precise location of the project on the site was pre-imported in the form of a mass map (Figure 14-D). The 3D model of the building is initiated by merging and recalibrating the different point clouds in a single CAD project (Figure 14-B). In addition, the BIM platform allows the visualisation of the project from any perspective through interior views (Figures 14-E & 14-F) and can be expanded directly to the VR display for realistic, textured and dynamic control (Figures.14-G & 14-H).

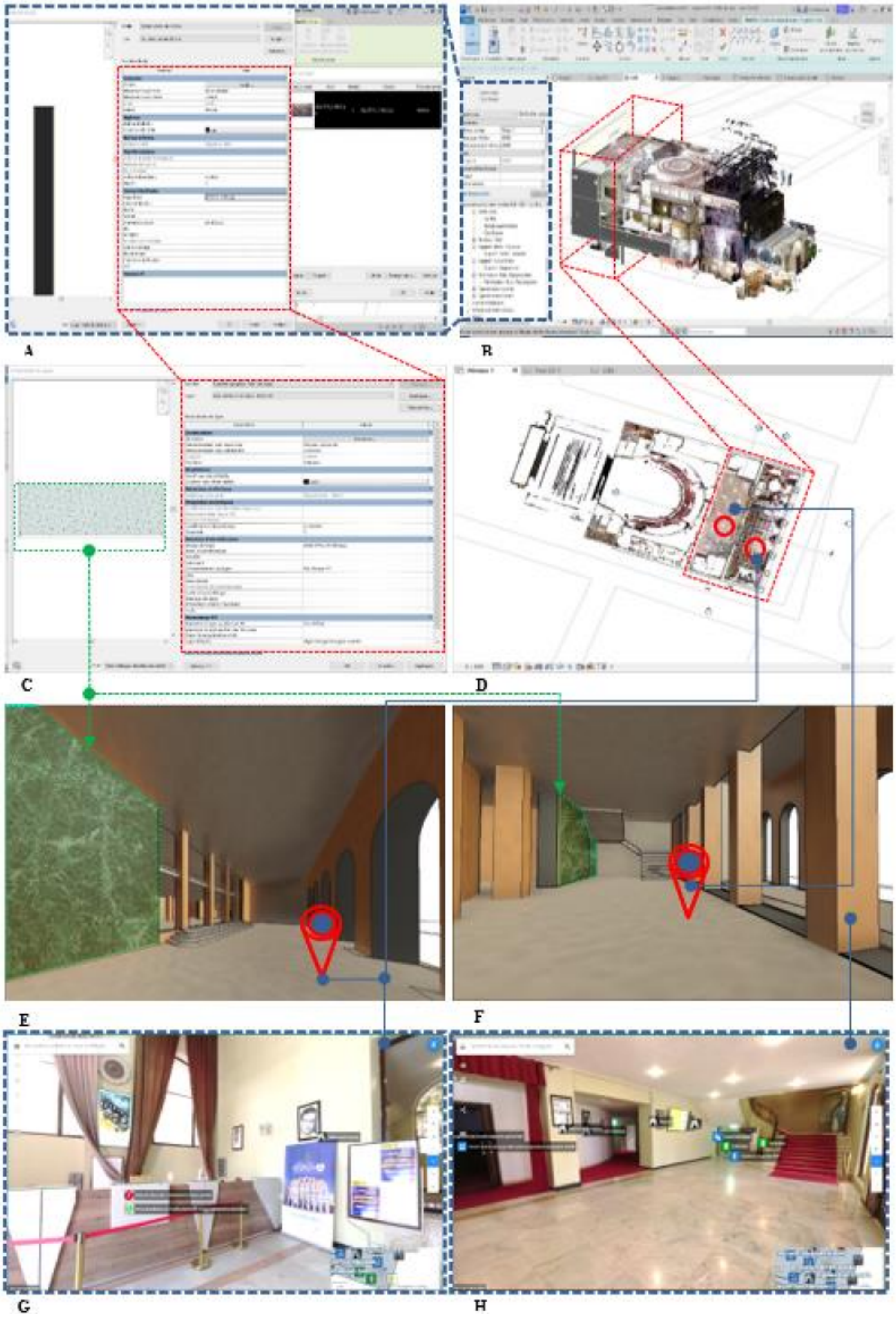


Figure 14: The Mahieddine Bachtarzi Theatre HBIM. (Source: Author, 2023). A- Configuration of constructive families; B- Merging point clouds and modelling; C- Assigning and settings of materials; D- Location on the site map, configuration of levels and construction; E- Rendered view of the public entrance hall; F- Rendered view of the distribution hall to the main auditorium and corridors; G- Screenshot of the public entrance hall displayed through VR; H- Screenshot of the distribution hall displayed through VR.

Figure 15 explains that this digital TNA model made it possible to obtain as needed and requested precise spatial, technical, and functional duplicates based on orthographic projections such as plans, cross-sections, and elevations. Thus, these multimetric outputs can cover a variety of functions that are not limited simply to management, control and operation, but also the BIM platform can generate and utilize other functionalities to automatically cover further simulation.

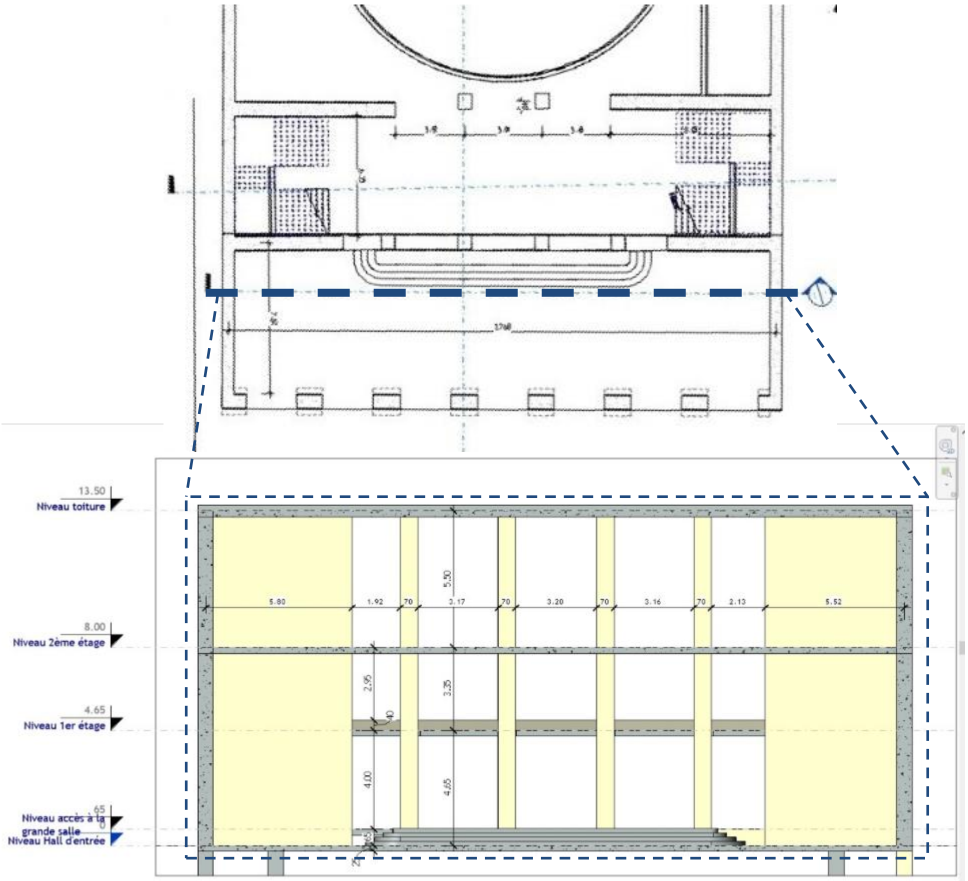


Figure 15: Architectural 2D blueprint and section showing the technical and constructive details in the main public hall of Mahieddine Bachtarzi Theatre produced in Revit©. (Source: Author, 2023).

5.1.2 AI-Assisted Processing

The Artificial intelligence platform (*The fastest way from Scan-to-BIM*, 2023) offers AI-assisted modelling. Thanks to the innovative workflow. It has improved component recognition and identification, assured quality control and reduced processing time. This tool has enabled the various elements to be identified as recognisable and sortable entities rather than surfaces.

By uploading the point clouds data to the platform, the trained AI algorithm fully automatically recognises the objects and retrieves their attributes. It finds the division into levels and the distribution of floors, as indicated in Figure 16-A. Processing generates a pre-modelled, interactive point cloud (Figure 16-B). Allowing the prototype to be handled and the various measurements and calculations to be carried out in all spatial directions, whatever the component or material (Figure 16-C).

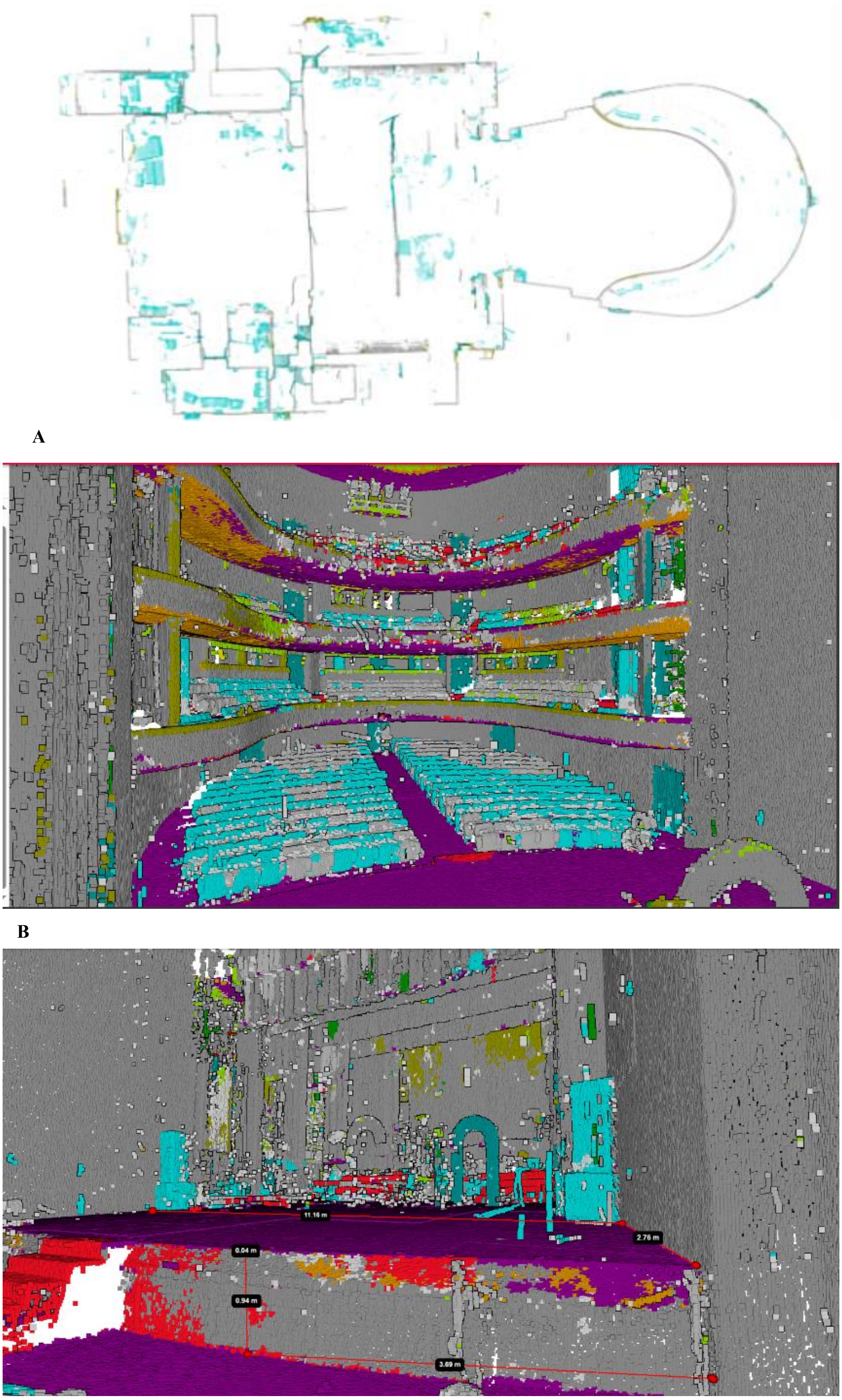


Figure 16: The recognition and classification of interior spaces using AI. (Source: Author, 2023.). A- Floor plan automatically identified; B- View of detailed composition over the seats and balconies; C- The space of the stage area divided and measured.

Subsequently, the model is organised according to a hierarchy distribution over independent layers. Which are distinguished by colour-coded classes as the Figure 17 explains. They are classified into 19 different groups such as walls, floors, windows, doors, speciality equipment, staircases, railings, structural framing and columns, roofs, site and terrain, clutter points, piping, furniture, lighting fixtures, vegetation, and missing parts that were not correctly covered by the laser beam during the recording steps. This set imitates CAD logic and enables its correct importation into the BIM–Revit© platform, organised according to its different internal families..

Figure 17: Mustapha Kateb Auditorium AI-assisted generation processing of architectural details. (Source: Author, 2023). A- Chromatic display extracted from scanning data; B- Semantic segmentation and components; C- Colour-coded system used for layers classification.

5.1.3 Interactive VR Experience

The NavVis-IVION Core (v 10.9.0, NavVis) animated reality data platform uses Amazon Web Services (AWS) for cloud hosting (*NavVis Knowledge Base*, 2023). Enabling the generation, sharing, and modification of the virtual TNA model. In addition, it geolocated the building based on the site coordinate system. It offers an available shared project to all stakeholders as well as other users from any web browser. That confirms today's digital transformation showcasing new ways of bringing architecture back to life and enabling a profound and diverse level of interactivity via a trio: the user, the information, and the space (Banfi, 2020; Bianconi *et al.*, 2023).

Digital restitution automatically identifies and generates floor plans using AI to create a TNA virtual replica. This provides an overview of the entire site and enables members to extend and enhance the project version, depending on the type of authorisation granted to them (Figure 25-Appendix B). Therefore, the proposed management framework is derived from the actual organisational and hierarchical needs of the cultural institution under study. A detailed analysis has uncovered a wide range of requirements that this research aims to address.The developer (licence holder) can update the VR version and add new data over time. All parties involved in the project are categorised into three types according to the diagram in Figure 18. The Administrator is responsible for handling the project and has permission to modify components or accept proposed changes. The second category relates to the Editor, who has access to specialised information input into the project by individuals appointed to carry out planned conservation or management tasks for the building. The last category is the Viewer. Allowing users to explore a detailed 3D model and discover spaces through a realistic display immerses them in the building. This enables a deeper understanding of its internal components and provides access to additional information stored in the documentary database.

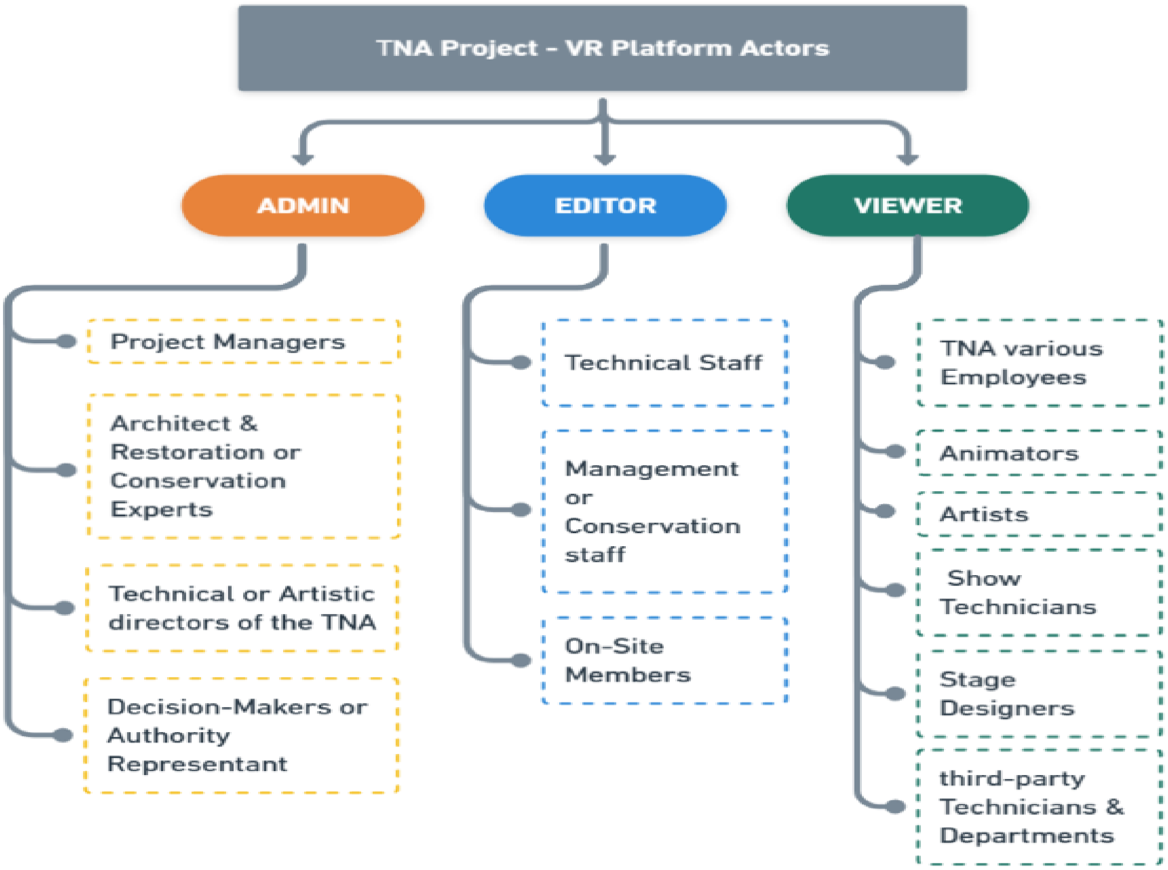


Figure 18. TNA-VR project stakeholders' and actors' categories and sub-categories. (Source: Author, 2023).

The virtual reconstruction of the TNA building was carried out by identifying the sub-components of the project. For the main auditorium *Mustapha Kateb* (Figure 19), we have classified the architectural units as follows: stage, backstage, auditorium seating, and balconies. Each space (Figure 19-A) has been delimited in plan and volume and can be parameterised and visualised as an independent entity in which information about surface area, height, volume, geometry and angle is accurately generated. The space delimiter is precise and can be adjusted to irregular and complex geometric shapes, such as curves, offering infinite tangential nodes (Figures 19-B, C & D).

In addition, integrating the NavVis-IVION add-in (v 2.2.1.0) into Revit© improved the As-Built HBIM workflow in synchronised mode. It also connects the BIM platform to realistic three-dimensional displays for each part of the TNA building (Figures 19-E, F & G).

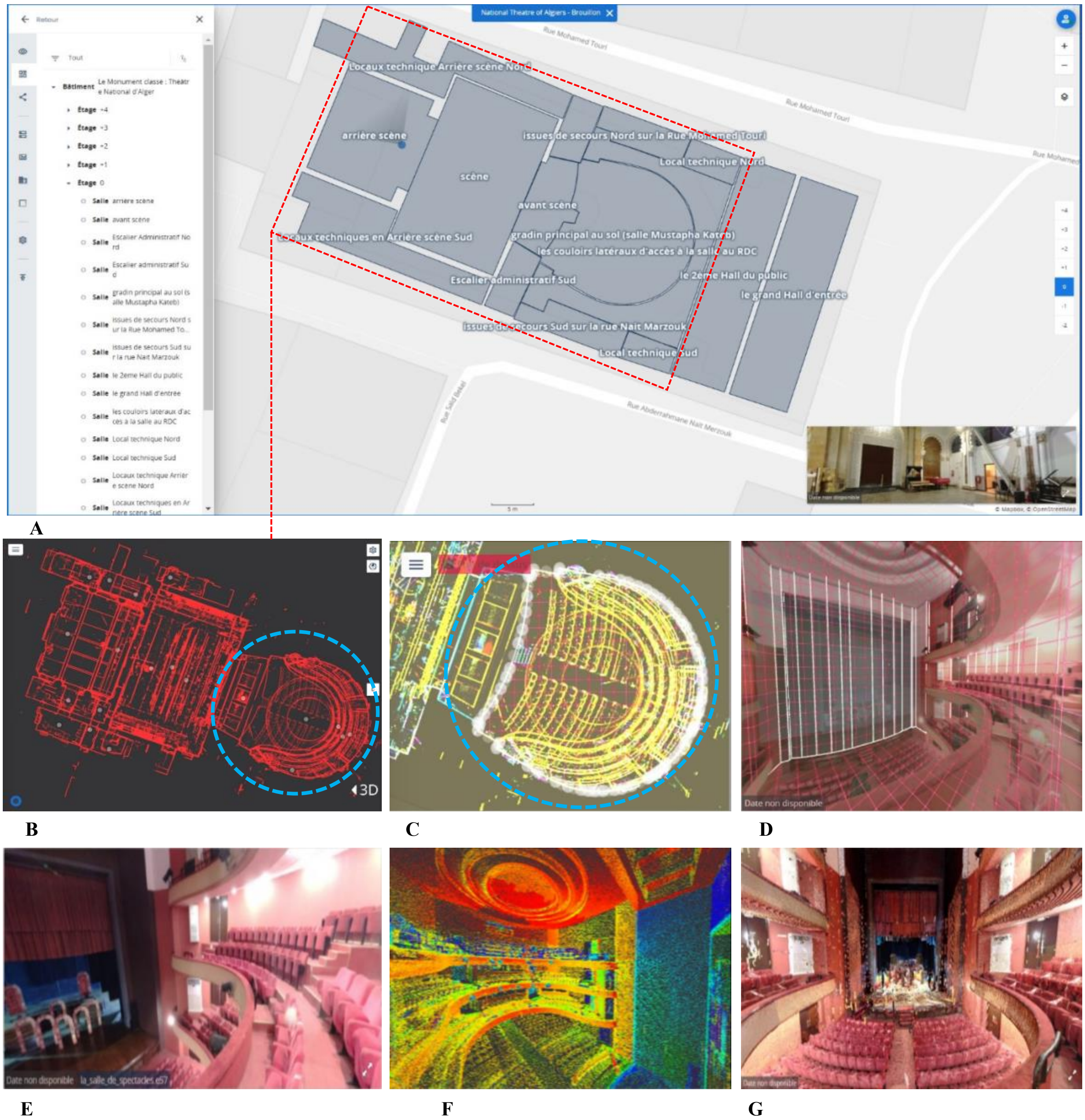


Figure 19: Alignment of data, segmentation of surfaces and creation of VR spatial independent entities of Mustapha Kateb Auditorium on NavVis IVION Core. (Source: Author, 2023). A- Georeferenced ground floor plan with all spatial components identified; B- Restitution of the show zone elements with precise waypoints; C- Delimitation and geometric definition of the space; D- The volume generated; E- The model displayed on textured mode; F- The model displayed in RGB mode; G- The model displayed on a superposed panoramic with a cloud layer.

6. DISCUSSION

The efficiency of the HBIM-assisted design combined with the tools and databases integrated into the project, allows the recognition and simulation of damaged or missed components of the building. This represents the changes the *Mahieddine Bachtarzi* Theatre building has undergone over the years. Because the HBIM provides the possibility of updating in the future by incorporating complementary information and empirical data, it offers an opportunity for retrospective work, while allowing for predictive planning to schedule interventions. As a result, stakeholders can interact at different levels based on different criteria. Following this logic, it is possible to examine the sustainability indicator and its association with the innovative management mode. Because the digitisation of heritage sites and buildings is under continuous development and depends on the future implications of technological prowess (Vital and Sylaiou, 2022). In addition, improving and managing digital assets depends on user feedback.

On the other hand, the point clouds acquired via As-Is recording can be viewed as a primitive 3D model. Allowing measurements on the architectural survey and the interior of the space to be visualised through cross-sections. The model display is either monochromatic or based on the colour intensity given to each point depending on the recording options, lighting conditions, textures, and target distance.

Despite the use of the Scan-to-BIM technique and previously mentioned capabilities in the DIGITAL TWIN section, recurrent on-site manipulation constraints, such as significant cost and equipment weight (Alshawabkeh, Baik and Miky, 2021) were encountered, that could limit the quality obtained from the point clouds. Considering the multi-purpose nature of the building, which serves a variety of administrative and entertainment functions, in addition to hosting cultural events such as exhibitions, shows, and performances, the scanning of the areas occupied by administrative/technical/artistic staff as well as the public had caused recording deficiencies such as a lack of registration data (Díaz-vilariño, Lagüela and Varela, 2016). In addition, colour quality depends on the capacity of the integrated recording cameras (Alshawabkeh, Baik and Miky, 2021), a factor that had only a minor impact on this study. However, manual verification was required (Liu *et al.*, 2023), because reflectivity, saturation, and darkness had a significant impact and necessitated further processing to remove edge discontinuities and noise.

Some factors limited the visibility inside the TNA building. These include furniture, height, size, architectural configuration, irregular components and reliefs, and the presence of some removable items, such as stage curtains and staging equipment, which obstruct the recording and require multiple scans registered from different positions and unified into a complementary set. In addition, As-Is restitution was a challenge, first in terms of authenticity due to the processing of old materials, then in terms of difficulty of access to high-risk and unsafe locations as well as occlusion concerns. Figure 20 shows some cases where areas were not adequately reached by the laser beam. Therefore, many spaces were not sufficiently covered by points (for multiple reasons, such as occupied by intensive activities or equipment/ narrow /unlit /buried underground or unhealthy).

A **B**

Figure 20: Some obstructed and unsafe areas not adequately covered by lasergrametry. (Source: Author, 2022). A- Cluttered and abandoned space; B- Underground boiler areas.

6.1 Immersive Experience, Critical Reflections

VR produced based on the As-Is captured model of the historical monument made it possible to clarify the heritage architecture and artefact for the benefit of a larger audience (Arrighi, See and Jones, 2021). Offering opportunities for innovative exploration to several categories of users, this underlines the fact that new technologies, such as laser scanning and advanced modelling (Banfi, 2020) have created a strong link between HBIM and VR. On the artistic and cultural side, it provided the means to organise events differently outside the constraints of physical space, or to reinterpret ancient performances from the available archives of iconic masterpieces that have been staged in the TNA for more than a century. The space exploration exposes an extension by supplementary non-geometric sources inherent to the model in addition to the morphology and the spacial-functional configuration. These have extended the model beyond the architectural and structural scope, opening it up to a new range of interests. Figure 21, presents an object from a historical collection that traces the itinerary of a particular cultural and theatrical period. It grants access to internal information integrated into autonomous exploration sections and complementary information via external links.

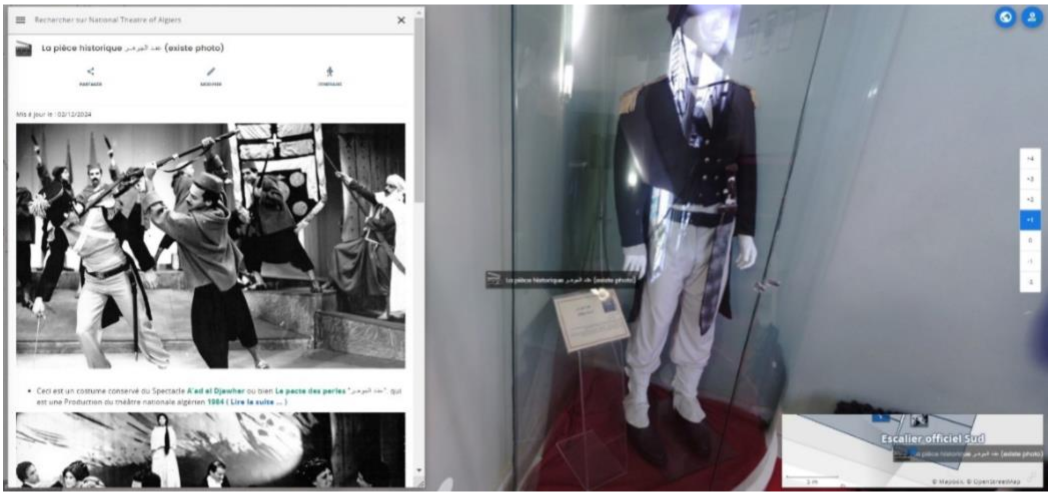


Figure 21: Example of integrated historical-artistic object and event information during the VR navigation. (Source: Author, 2023).

Another role of NavVis IVION Core for TNA-VR restitution is to place the user in a realistic digital environment browsing 360° panoramic views that faithfully represent their real context. Visitors can discover countless locations, including hidden and restricted areas they have never been able to see inside the TNA. They walk through the entire building using free movement during the interactive navigation, based on pre-established connections between all spaces and levels in the VE (Figure 22). The user is immediately teleported to the location following the point-and-click technique (Shahbaz Badr and De Amicis, 2023), in the same time location tracking on the mini-view map permits a simultaneously itinerary identification.

The implementation of AI is a turning point in this approach to heritage preservation. Its use simplified and accelerated the process of creating 3D models from laser scan data. Improving accuracy while shortening the time and labour needed for manual modelling. A revealing initiative was carried out in the *Mahieddine Bachtarzi* Theatre, a 19th-century building in the heart of Algiers, where this approach led to the realisation of the TNA-Digital Twin project. In addition, it highlighted the potential of cutting-edge technologies to meet the challenge of heritage management by promoting the interaction between RC and software throughout the process, ranging from automatic recognition to synchronised display of the project. The AI used in this study is certainly trained to recognise architectural and structural elements. However, we found that the identification of certain parts is confusing, especially in spaces with large surface areas and heights. This complexity makes it difficult to distinguish the attributes inherent to each point, requiring manual verification and redirection. Therefore, it should be a priority to clean up the raw point cloud during preprocessing.

Regarding technical and architectural aspects, VR has made it possible to have an overview and rigorous up-to-date monitoring of the building. In terms of its current conservation state, its occupation, its transformation, or even its degradation. In addition to planning specific initiatives, obviously, at different levels, whether structural, aesthetic or equipment. All interest items, including among others stairways, service areas, restrooms, reception desks, entrances, and emergency exits, are defined and precisely indicated on the project by creating and managing points of interest (POIs). Through the various areas and spaces (2D or 3D), these data can be communicated for specific purposes. Examples include security installations or specific scenic lighting arrangements for the show zone created for the auditorium, hallways, and public walkways.

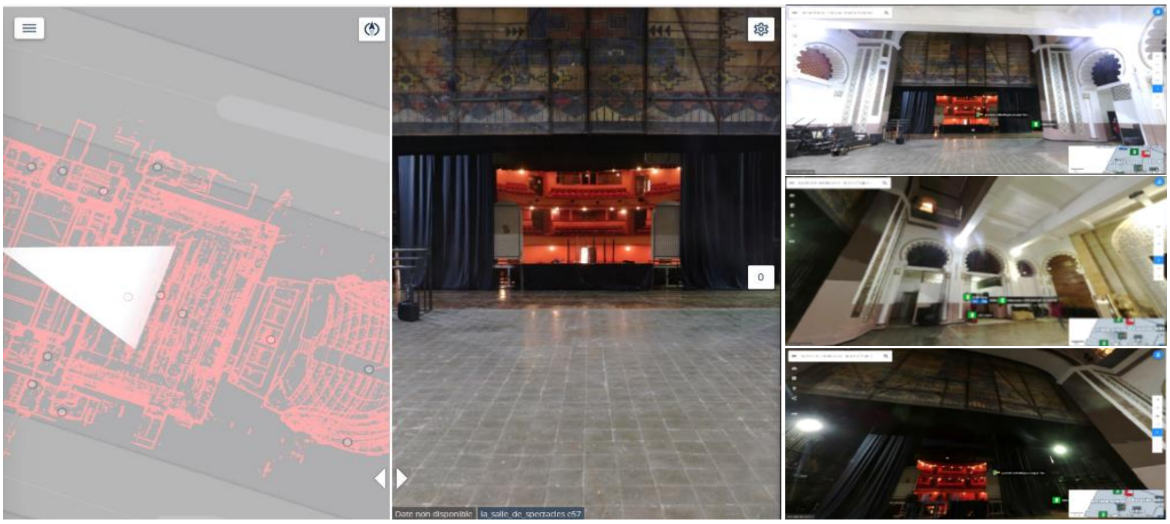


Figure 22: Backstage exploration on VR through synchronised 2D and 3D viewing modes. (Source: Author, 2023).

To coordinate interventions for effective implementation, it is also necessary to synchronise data with relevant outsourced services and third parties. To take action or plan measures based on reliable and accurate data available on the VR platform. It has been suggested that the efficient management of heritage sites can be achieved through remote access to staff who can ensure security and reduce the various risks (Santana Quintero, Duong and Smith, 2022). We mention the example of fire-safety system management, with precise positioning of devices and their geo-referenced location is shareable with internal or external users (through an Excel file (*.xls*) as detailed in Figure 26-Appendix C) delivered through the generation of the digital duplication. The system is divided between fire stations, fire extinguishers and emergency exits as presented in Figure 23. This is a major concern for such a monument, given its size, architectural and urban layout, historical importance and, above all, the fact that its construction materials are particularly vulnerable. Thanks to the TNA-VR model, it was possible to determine the itineraries to and from different locations with precise predetermined markers. All measurements are computed in three directions (X, Y, and Z) on the As-Is model and can be added for any purpose.

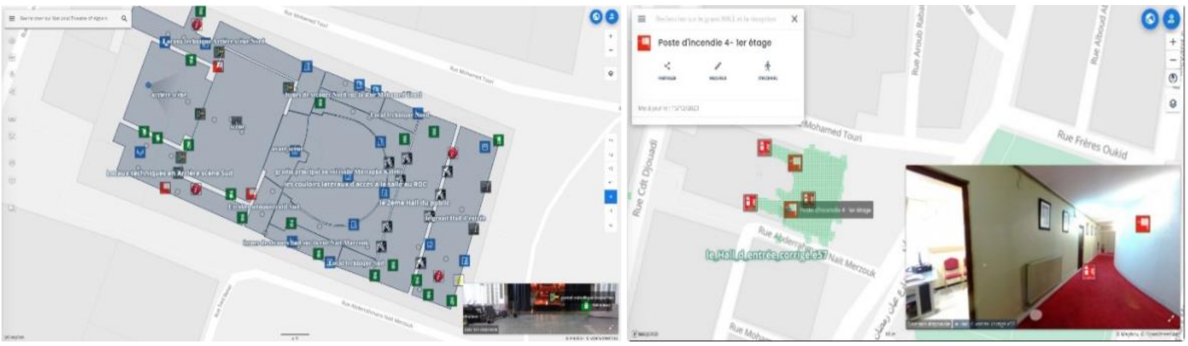


Figure 23: Example of fire-safety system distribution structured through different floors. (Source: Author, 2023).

6.2 Digital Twin Flowchart

Figure 24 depicts the conversion of the *Mahieddine Bachtarzi* Theatre into a digital twin (TNA-DT). Following a general flowchart, the workflow was summarised. This model illustrates the software used and their proposed interoperability. It also explains the hierarchy of the three main phases distributed between the first stage relating to As-Is documentation and As-Built recovery. Followed by a second stage related to enhanced processing. Culminating in the third stage, which pertains to the HBIM process generating a digital twin. Thus, the recommended links are balanced between a deductive frame and an iterative frame to bring the various inputs into a synergistic relationship, leading to a BIM assisted by AI and enriched by VR.

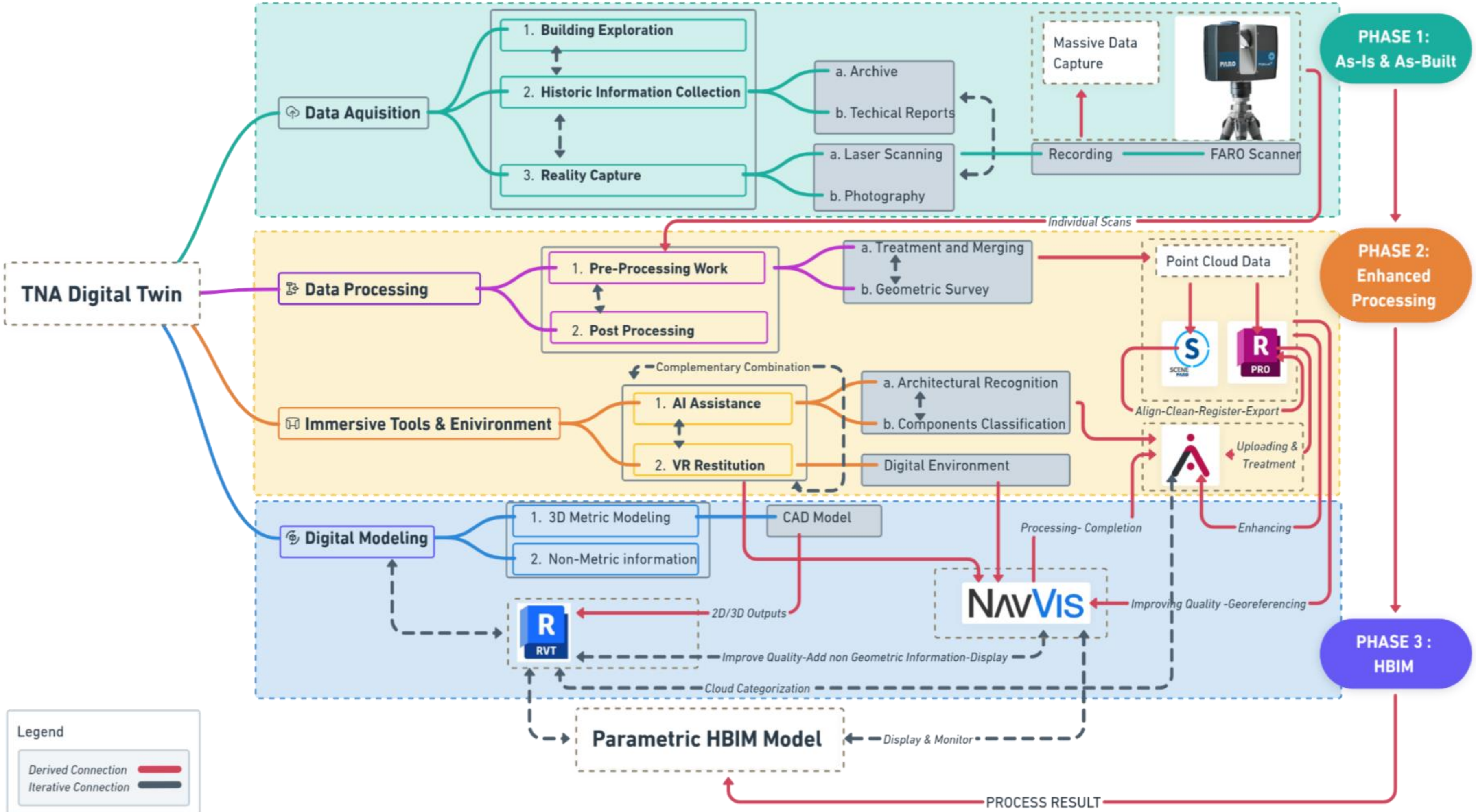


Figure 24: Optimised Workflow Diagram for TNA Digital Twin. (Source: Author, 2023).

7. CONCLUSION

The emerging concept of digital twin for heritage monuments and sites leads to effective convincing and practical solutions. Therefore, there is a need to digitalise the current state of the site and artefact to preserve the traces and markers of time at a precise moment during its temporal and cultural evolution. Such an approach highlights built heritage capacity to serve as a bridge linking different eras through its morphology while preserving its story-telling impact. This revolutionary new approach to CH (Pansoni *et al.*, 2023), is underpinned by technological and digital advances, enabling it to be discovered by the widest possible interested people without physical or geographical barriers. Accordingly, the use of immersive technologies adds value to the recognition of classified heritage assets in the Algerian context. It increases the consideration of both tangible and intangible aspects, by initiating their preservation through the creation and sharing of digital content and experience. Supported by the intervention of AI and the restitution of VR in an interconnected and mutually interchangeable system, the DT provides regular assessments and updates essential for management of the historic building.

The TNA-DT (Figure 24) explored sequences for an advanced Scan-to-BIM framework. This computational method, grounded in laser scanning and point clouds, significantly enhances the enrichment and accuracy of resilient and sustainable heritage documentation by retrieving and substituting missing resources. It finalised the As-Built version, providing a foundation for the regeneration of the monument, which had previously lacked reliable technical and graphical resources. Through an accurate HBIM extended to a virtual reality environment, connection and direct synchronisation were possible with the source CAD project. This advanced gateway opens up new possibilities to facilitate real-time management and monitoring, in which automated and manual approaches mutually complement each other. However, there is a growing need to automate data collection and subsequent preprocessing, a factor that facilitates the procedure and saves time for 3D modelling from clouds. As well as for identifying objects and ensuring that they fit easily into the VE. The lessons learned from the theatre, which is the central subject of this research, can be applied to other forms of cultural spaces, where VR could effectively manage and showcase these buildings to a broad audience. In particular, web-based VR allows for real-time updates without disruption during use and facilitates interaction and sharing of materials; therefore, users do not require any specialised hardware or VR equipment, as the experience is compatible with all internet web or mobile browsers, across any device (computer, collaborative screen, tablet, and phone).

The proposed workflow sums up an integrated approach and ensures streamlined and efficient data processing combined with other additional or complementary datasets. In light of the fact that CH role has been extended to simulate a silent witness (Alexakis *et al.*, 2019), it acts as an on-life stamp of past know-how, this is how digital replication is an infinite virtual representation exploited over time, and enriched through sensors or data automatically synchronised across different platforms for a perpetual transmission. Integrating AI for recognition and classification into the workflow has shown a substantial effect. Such a process was a key factor and was able to automatically supply many of the human-intensive tasks involved in manual modelling, like data processing and feature extraction, thus saving time and effort (Figure 8). The use of the ML algorithm further enhanced the density of the point clouds. The components were completed by indicating and aligning the proposed points in a seamless continuation as segments and surfaces. The algorithm successfully restored the point path in specific areas where the recording was technically incomplete or had insufficient coverage. AI forms an extensive step in HBIM, ensuring its fluidity and accentuating the efficiency and details of the model. We also improved it by using an interoperable web-based VR platform to verify and upgrade the accuracy of the point clouds while creating the prototype.

This research proposes a methodology to digitise classified historical monuments and emphasises the importance of digital architectural surveys. It serves as a practical guide for researchers, technical practitioners, and administrators to implement a strategy in which creating a digital twin based on the advanced Scan-to-BIM method provides various flexible and scalable scenarios to meet their specific needs, as revealed by the surveys and interviews. In addition, it highlights the capacity for engagement of various heritage stakeholders via the proposed interactive model. Therefore, such collaborations bridge the gap between analysis, decision-making, and the actual condition of the building. The public and tourists have an opportunity to explore the entire building free of charge, including non-accessible and restricted areas, such as the backstage or the sub-stage, the pavilions for artists and VIPs, along with the rehearsal and technical spaces. Furthermore, visitors can discover off-site archives, theatre pieces, exhibitions, and services as alternatives or complements to traditional on-site events and visits, promoting cultural enrichment. Exploring its tourism potential, regenerating the building, and increasing interest and profit through the attractiveness of heritage could lead to passive conservation and economic benefits.

7.1 Model Validation

The study confirmed the effectiveness of the enhanced Scan-to-BIM workflow using ML, as demonstrated by the enhanced Scan-to-BIM framework in Figure 13. AI has improved the quality and reliability of models by enabling a fluid and supervised transition between preprocessed point clouds and parametric CAD models based on the graphical and geometric attributes associated with each captured point. The HBIM achieved is a complementary effort to those existing in the digitisation of buildings and research on automatic flows, through an interactive approach extended to the digital twin where the 3D model is interconnected with VR. Consequently, it can deliver a system with updatable features offering dynamic and reactive control, while addressing the historical, cultural, technical, and economic criteria.

Here, the digital twin creates a realistic environment that can be extended as required for tangible (monuments, sites, or objects) and intangible heritage. This will bestow a new lease of life on cultural heritage alongside its material existence by adding additional functionalities compared with the traditional conservation approaches. It refers to harmonised and multimodal management and preservation strategies, off-site planning of relocated activities, virtual visits, real-time monitoring, and online access to spaces and data. In addition, we validated a dissemination approach aimed at user-testers from various categories of audience to understand the overall impact of the immersive experience on the understanding and appreciation of the heritage building.

The obtained results underscore the role of digitisation in promoting built heritage preservation. Immersive technologies offer innovative interpretation through emerging correlations between various actors and techniques. Based on surveying the administrative hierarchy, we identified the stakeholders involved in the project according to their assigned roles, and then categorised them into sub-groups, as shown in Figures. 18 & 25. Interactions between them allow informed decisions by authorities or decision-makers and even extend to third parties (as explained in the DISCUSSION section), represented by people and services in dispersed administrative structures with responsibilities and agendas that differ from one another. These include the Ministry of Culture and its technical departments, local authorities, NGOs and associations, and the administration of the building. Whether it concerns the building itself or a project on the site, such as cultural or artistic events or various conservation operations. In this case, the BIM serves with real-time data input synced by the implementers (architects, technical staff, managers or curators). Subsequently, the TNA-HBIM process is an iterative cycle that strengthens and shortens the links between successive reverse engineering stages. It is possible to implement a synergy that can generate protection by conserving heritage value in all its tangible and intangible richness, as we have seen from the studied case facing threats and degradation due to the effects of age, use and nature. Immediate feedback via remote virtual visit functions is now possible.

7.2 Practical Implications

Immersive experience improves recording techniques for cultural heritage, using AI as a catalyst for quality, efficiency and simulation techniques that have given rise to the digital conversion of complex heritage buildings (Banfi, 2020). By adhering to the proposed Algiers national theatre workflow and utilising the AI-assisted pre-categorised architectural library for CAD models, this method optimises the efficacy and applicability of HBIM to support 19th-century neoclassical monument conservation projects in Algeria.

This study is committed to revealing a heritage relatively obscure to the public through VR. Which provides a technical platform enriched with the data needed by informed users and even virtual tours intended for various visitors. The experience conducted on the NavVis IVION Core platform offers an in-situ exploration of the building and, at the same time, gives the possibility of discovering the restitution of historical shows and art pieces displayed with high fidelity. Able to be transformed into an active VR and expand the workflow to augmented reality (AR) (Pervolarakis *et al.*, 2023) or extended reality (XR).

7.3 Limitations

Despite the capabilities and evidence that immersive technology offers CH, in addition to the need for specialist knowledge and expertise, its high cost is a barrier to its implementation and widespread adoption. It starts with unaffordable equipment and fee-based software and platforms. Also, the relevant platforms require specific algorithms and process cases individually.

The use of AI in this study helped with the recognition and segmentation of physical structural components such as walls, floors, doors, windows and columns, it still required time-consuming manual work on the BIM. More precisely the algorithm is not yet trained to recognise the various components autonomously. Especially with particular details such as woodwork decorations or vaulted structure systems. Moreover, this algorithm is currently only capable of recognising interior spaces.

7.4 Suggestions for Future Research

Linking the topics of 3D digitisation, AI, and Immersive duplication incidence on cultural heritage revealed that advanced digital technologies are a 21st-century marker point. It belongs to highly dynamic and exponential development. AI is a burgeoning technology in cultural heritage that can be difficult to cover comprehensively in such a study. The current investigation pointed out possible extensive directions. So, the main orientation for future research requires validation of current AI applications through further efforts to explore trained algorithms to achieve recognition considering the complexity of morphologies, textures and the building façades, based on ML that is continuously enriched by input and user feedback. Further studies will examine how users' VR experience can advance into XR and AR.

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APPENDICES

APPENDIX A. TECHNICAL SPECIFICATIONS OF THE USED STATIC TLS

Table.1 shows the main information to consider about the RC equipment employed to realise the architectural survey.

Table : FARO Focus^{s}350 technical characteristics. (Source: Author, 2022).

Ranging Unit	614 m for up to 0.5 mil pts/sec	
(unambiguity interval	307 m at 1 mil pts/sec	
Range Covered	white surface	black surface
	0.6-350 m	0.6-50 m
	90 % of reflectivity	02 % of reflectivity
Angular Accuracy	for vertical/horizontal angles	
	19"	
3D Point Accuracy	2 mm for a coverage of 10 m	3.5 mm for a distance of 25 m

APPENDIX B. ASSIGNMENT OF ROLES

Figure 25 illustrates the roles and responsibilities assigned to participants in the TNA-VR Project.

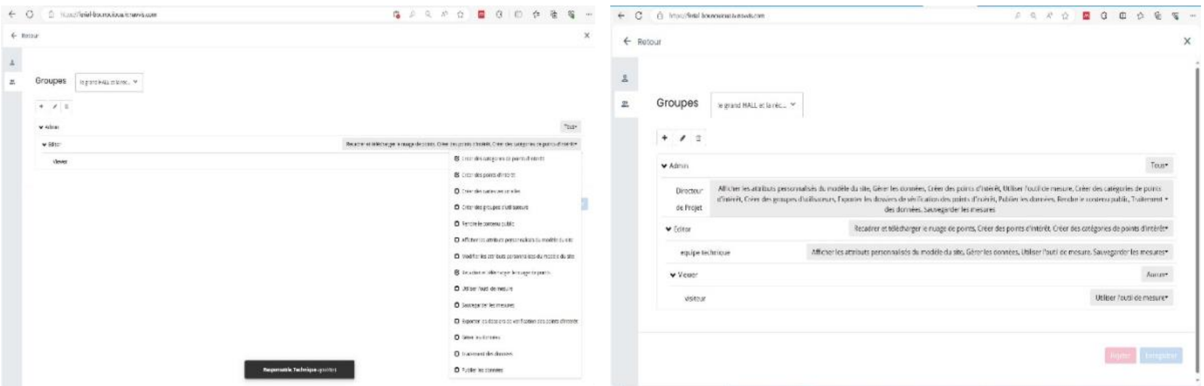
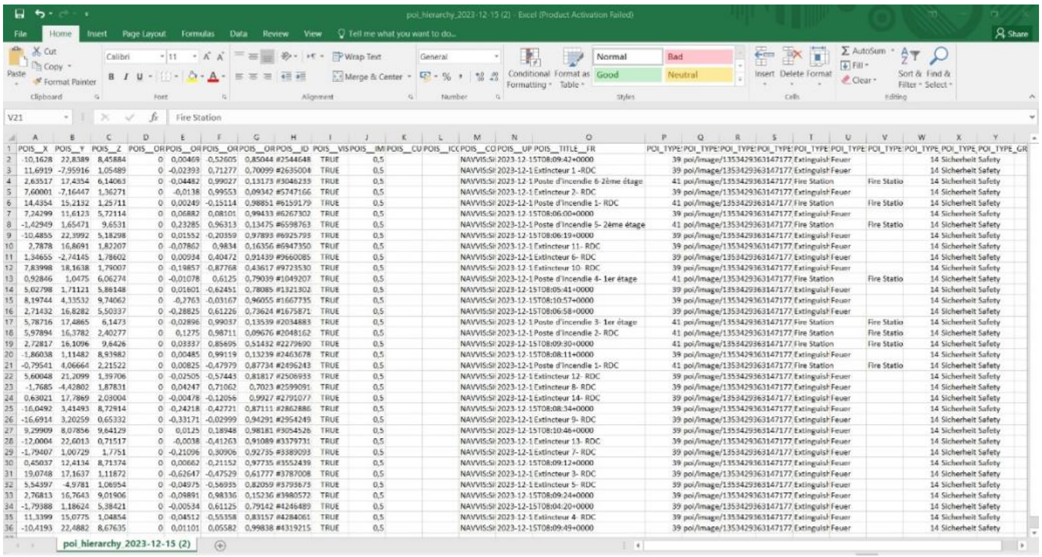


Figure 25: The different user groups and roles integrated on the NavVis IVION Core platform. (Source: Author, 2023).

APPENDIX C. FIRE-SAFETY SYSTEM

Figure 26 explains the different fire-safety systems, with nomination, level and precise position.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
1	POIS__X	POIS__Y	POIS__Z	POIS__OR	POIS__OR	POIS__OR	POIS__OR	POIS__ID	POIS__VIS	POIS__IM	POIS__CU	POIS__ICC	POIS__CO	POIS__UP	POIS__TITLE__FR	POI_TYPE	POI_TYPE	POI_TYPE	POI_TYPE	POI_TYPE	POI_TYPE	POI_TYPE	POI_TYPE	POI_TYPE	POI_TYPE_GR
2	-10,1628	22,8389	8,45884	0	0,00469	-0,52605	0,85044	#2544648	TRUE	0,5			NAVVIS:Si	2023-12-15T08:09:42+0000		39	poi/image/1353429363147177			Extinguis	Feuer		14	Sicherheit	Safety
3	11,6919	-7,95916	1,05489	0	-0,02393	0,71277	0,70099	#2635004	TRUE	0,5			NAVVIS:Si	2023-12-1	Extincteur 1 -RDC	39	poi/image/1353429363147177			Extinguis	Feuer		14	Sicherheit	Safety
4	2,63517	17,4354	6,14063	0	-0,04482	0,99027	0,13173	#3046233	TRUE	0,5			NAVVIS:Si	2023-12-1	Poste d'incendie 6-2ème étage	41	poi/image/1353429363147177			Fire Station		Fire Statio	14	Sicherheit	Safety
5	7,60001	-7,16447	1,36271	0	-0,0138	0,99553	0,09342	#5747166	TRUE	0,5			NAVVIS:Si	2023-12-1	Extincteur 2- RDC	39	poi/image/1353429363147177			Extinguis	Feuer		14	Sicherheit	Safety
6	14,4354	15,2132	1,25711	0	0,00249	-0,15114	0,98851	#6159179	TRUE	0,5			NAVVIS:Si	2023-12-1	Poste d'incendie 1- RDC	41	poi/image/1353429363147177			Fire Station		Fire Statio	14	Sicherheit	Safety
7	7,24299	11,6123	5,72114	0	0,06882	0,08101	0,99433	#6267302	TRUE	0,5			NAVVIS:Si	2023-12-15T08:06:00+0000		39	poi/image/1353429363147177			Extinguis	Feuer		14	Sicherheit	Safety
8	-1,42949	1,65471	9,6531	0	0,23285	0,96313	0,13475	#6598763	TRUE	0,5			NAVVIS:Si	2023-12-1	Poste d'incendie 5- 2ème étage	41	poi/image/1353429363147177			Fire Station		Fire Statio	14	Sicherheit	Safety
9	-10,4855	22,3992	5,18298	0	0,01552	-0,20359	0,97893	#6925793	TRUE	0,5			NAVVIS:Si	2023-12-15T08:06:19+0000		39	poi/image/1353429363147177			Extinguis	Feuer		14	Sicherheit	Safety
10	2,7878	16,8691	1,82207	0	-0,07862	0,9834	0,16356	#6947350	TRUE	0,5			NAVVIS:Si	2023-12-1	Extincteur 11- RDC	39	poi/image/1353429363147177			Extinguis	Feuer		14	Sicherheit	Safety
11	1,34655	-2,74145	1,78602	0	0,00934	0,40472	0,91439	#9660085	TRUE	0,5			NAVVIS:Si	2023-12-1	Extincteur 6- RDC	39	poi/image/1353429363147177			Extinguis	Feuer		14	Sicherheit	Safety
12	7,83998	18,1638	1,79007	0	-0,19857	-0,87768	0,43617	#9723530	TRUE	0,5			NAVVIS:Si	2023-12-1	Extincteur 10- RDC	39	poi/image/1353429363147177			Extinguis	Feuer		14	Sicherheit	Safety
13	0,92846	1,0475	6,06274	0	-0,01078	0,6125	0,79039	#1049207	TRUE	0,5			NAVVIS:Si	2023-12-1	Poste d'incendie 4- 1er étage	41	poi/image/1353429363147177			Fire Station		Fire Statio	14	Sicherheit	Safety
14	5,02798	1,71121	5,86148	0	0,01601	-0,62451	0,78085	#1321302	TRUE	0,5			NAVVIS:Si	2023-12-15T08:05:41+0000		39	poi/image/1353429363147177			Extinguis	Feuer		14	Sicherheit	Safety
15	8,19744	4,33532	9,74062	0	-0,2763	-0,03167	0,96055	#1667735	TRUE	0,5			NAVVIS:Si	2023-12-15T08:10:57+0000		39	poi/image/1353429363147177			Extinguis	Feuer		14	Sicherheit	Safety
16	2,71432	16,8282	5,50337	0	-0,28825	0,61226	0,73624	#1675871	TRUE	0,5			NAVVIS:Si	2023-12-15T08:06:58+0000		39	poi/image/1353429363147177			Extinguis	Feuer		14	Sicherheit	Safety
17	5,78716	17,4865	6,1473	0	-0,02896	0,99037	0,13539	#2034883	TRUE	0,5			NAVVIS:Si	2023-12-1	Poste d'incendie 3- 1er étage	41	poi/image/1353429363147177			Fire Station		Fire Statio	14	Sicherheit	Safety
18	5,97894	16,3782	2,40277	0	0,1275	0,98711	0,09676	#2048162	TRUE	0,5			NAVVIS:Si	2023-12-1	Poste d'incendie 2- RDC	41	poi/image/1353429363147177			Fire Station		Fire Statio	14	Sicherheit	Safety
19	2,72817	16,1096	9,6426	0	0,03337	0,85695	0,51432	#2279690	TRUE	0,5			NAVVIS:Si	2023-12-15T08:09:30+0000		41	poi/image/1353429363147177			Fire Station		Fire Statio	14	Sicherheit	Safety
20	-1,86038	1,11482	8,93982	0	0,00485	0,99119	0,13239	#2463678	TRUE	0,5			NAVVIS:Si	2023-12-15T08:08:11+0000		39	poi/image/1353429363147177			Extinguis	Feuer		14	Sicherheit	Safety
21	-0,79541	4,06664	2,21522	0	0,00825	-0,47979	0,87734	#2496243	TRUE	0,5			NAVVIS:Si	2023-12-1	Poste d'incendie 1- RDC	41	poi/image/1353429363147177			Fire Station		Fire Statio	14	Sicherheit	Safety
22	5,60048	21,2099	1,39706	0	-0,02505	-0,57443	0,81817	#2506933	TRUE	0,5			NAVVIS:Si	2023-12-1	Extincteur 12- RDC	39	poi/image/1353429363147177			Extinguis	Feuer		14	Sicherheit	Safety
23	-1,7685	-4,42802	1,87831	0	0,04247	0,71062	0,7023	#2599091	TRUE	0,5			NAVVIS:Si	2023-12-1	Extincteur 8- RDC	39	poi/image/1353429363147177			Extinguis	Feuer		14	Sicherheit	Safety
24	0,63021	17,7869	2,03004	0	-0,00478	-0,12056	0,9927	#2791077	TRUE	0,5			NAVVIS:Si	2023-12-1	Extincteur 14- RDC	39	poi/image/1353429363147177			Extinguis	Feuer		14	Sicherheit	Safety
25	-16,0492	3,41493	8,72914	0	-0,24218	-0,42721	0,87111	#2862886	TRUE	0,5			NAVVIS:Si	2023-12-15T08:08:34+0000		39	poi/image/1353429363147177			Extinguis	Feuer		14	Sicherheit	Safety
26	-16,6914	3,20259	0,65332	0	-0,33171	-0,02999	0,94291	#2954249	TRUE	0,5			NAVVIS:Si	2023-12-1	Extincteur 9- RDC	39	poi/image/1353429363147177			Extinguis	Feuer		14	Sicherheit	Safety
27	9,29909	8,07856	9,64129	0	0,0125	0,18948	0,98181	#3054526	TRUE	0,5			NAVVIS:Si	2023-12-15T08:10:46+0000		39	poi/image/1353429363147177			Extinguis	Feuer		14	Sicherheit	Safety
28	-12,0004	22,6013	0,71517	0	-0,0038	-0,41263	0,91089	#3379731	TRUE	0,5			NAVVIS:Si	2023-12-1	Extincteur 13- RDC	39	poi/image/1353429363147177			Extinguis	Feuer		14	Sicherheit	Safety
29	-1,79407	1,00729	1,7751	0	-0,21096	0,30906	0,92735	#3389093	TRUE	0,5			NAVVIS:Si	2023-12-1	Extincteur 7- RDC	39	poi/image/1353429363147177			Extinguis	Feuer		14	Sicherheit	Safety
30	0,45037	12,4134	8,71374	0	0,00662	-0,21152	0,97735	#3552439	TRUE	0,5			NAVVIS:Si	2023-12-15T08:09:12+0000		39	poi/image/1353429363147177			Extinguis	Feuer		14	Sicherheit	Safety
31	19,0748	17,1637	1,11872	0	-0,62647	-0,47529	0,61777	#3787008	TRUE	0,5			NAVVIS:Si	2023-12-1	Extincteur 3- RDC	39	poi/image/1353429363147177			Extinguis	Feuer		14	Sicherheit	Safety
32	5,54397	-4,9781	1,06954	0	-0,04975	-0,56935	0,82059	#3793673	TRUE	0,5			NAVVIS:Si	2023-12-1	Extincteur 5- RDC	39	poi/image/1353429363147177			Extinguis	Feuer		14	Sicherheit	Safety
33	2,76813	16,7643	9,01906	0	-0,09891	0,98336	0,15236	#3980572	TRUE	0,5			NAVVIS:Si	2023-12-15T08:09:24+0000		39	poi/image/1353429363147177			Extinguis	Feuer		14	Sicherheit	Safety
34	-1,79388	1,18624	5,38421	0	-0,00534	0,61125	0,79142	#4246489	TRUE	0,5			NAVVIS:Si	2023-12-15T08:04:20+0000		39	poi/image/1353429363147177			Extinguis	Feuer		14	Sicherheit	Safety
35	11,3399	15,0775	1,04854	0	-0,04512	-0,55358	0,83157	#4284061	TRUE	0,5			NAVVIS:Si	2023-12-1	Extincteur 4- RDC	39	poi/image/1353429363147177			Extinguis	Feuer		14	Sicherheit	Safety
36	-10,4193	22,4882	8,67635	0	0,01101	0,05582	0,99838	#4319215	TRUE	0,5			NAVVIS:Si	2023-12-15T08:09:49+0000		39	poi/image/1353429363147177			Extinguis	Feuer		14	Sicherheit	Safety

poi_hierarchy_2023-12-15 (2)

Figure 26: Precise coordinates of distributed fire protection equipment throughout the public hall areas. (Source: Author, 2023).

APPENDIX D. NOMENCLATURES

1. ACRONYMS

AEC	Architecture, Engineering, and Construction
AI	Artificial Intelligence
ANN	Artificial Neural Network
ANSS	National Agency for Safeguarded Sectors
AR	Augmented Reality
BIM	Building Information Modelling
CAD	Computer-Aided Design
CH	Cultural Heritage
DCH	Digital Cultural Heritage
DE	Digital Environment
DT	Digital Twin
HBIM	Historic or Heritage Building Information Modelling
LC	Life Cycle
LIDAR	Light Detection and Ranging
MDC	Massive Data Capture
ML	Machine Learning
RC	Reality Capture
TLS	Terrestrial Laser Scanning
TNA	Algerian National Theatre
VE	Virtual Environment
VR	Virtual Reality
XR	Extended Reality

2. SYMBOLS / PARAMETERS

RGB: Red, Green, and Blue
″: Arcsecond = 1/3600 of a degree