Architectural Heritage Exploration and Visualization Using Interactive and Immersive Technologies

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ABSTRACT

The Historic District of Jeddah (HDJ) of the Kingdom of Saudi Arabia, is facing many challenges to attain conservation and sustainability, due to natural disasters and the absence of appropriate digital recordings and documentation. Previous studies on world heritage conservation attempted to address these challenges while adopting the immersive and visual technologies separately or via merging one of them with another to conserve the heritage sites (e.g. BIM/GIS integration or generating GIS/BIM, integrating VR with BIM, or GIS). However, few of these studies handled the case of the historic heritage of KSA.

This research aims to fill this gap by utilizing all these technologies together to create an immersive visualization system for heritage sites. The researcher proposes a novel method using immersive technologies (VR, AR, MR) and visualization methods (3D modeling) combined with Heritage Building Information Modelling (HBIM) and Heritage Geographic Information Systems (HGIS) for comprehensive conservation of cultural heritage sites in Saudi Arabia. The proposed method involves three phases: a) **HBIM and HGIS generation:** This involves creating 3D architectural models and spatial data using industry-standard collection tools, b) **HBIM and HGIS Integration:** The data from both phases is merged into a single georeferenced system for unified analysis, and c) **Interactive User Experience:** An interactive user environment is developed using a game engine, allowing users to explore the 3D model and access historical information.

This research offers a multi-disciplinary approach to cultural heritage conservation, combining innovative informatics with technology for documentation, communication, and user engagement. The findings will enable users to virtually explore the heritage sites and track

changes over time. This immersive experience fosters a deeper understanding and appreciation of the architectural heritage. The proposed method can be applied to other cultural heritage sites globally. Future studies could explore using 3D viewers for information retrieval and potentially using CityGML, a rich 3D geospatial data format, for even more comprehensive HBIM-HGIS integration. This would significantly contribute to the advancement of world heritage conservation efforts.

DECLARATION

I hereby declare that the contents and organization of this dissertation constitute my original work and do not compromise in any way the rights of third parties, including those relating to the security of personal data.

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ACRONYMS

3D - 3 Dimensions

AECO - The Architecture, Engineering, Construction, and Owner/Operator industry

Ain el Abd UTM Zone 37N - Spatial Reference

AR - Augmented Reality

AVR - Augmented and Virtual Reality

BIM - Building Information Modeling

CAD - Computer Aided Design

COTS - Commercial Off-The-Shelf

CRP - Close-Range Photogrammetry

DEM - Digital Elevation Model

DV - Dependent Variable

EEEF - Effectiveness, Extensibility, Effort, and Flexibility

ETL - Extract, Transform, and Load

GIS - Geographic Information system

GPS - Global Positioning System

HBIM - Historic Building Information Modeling

HDJ - Historic District of Jeddah City

HGIS - Historic Geographic Information System

HIA - Heritage Impact Assessment

IFC - Industry Foundation Classes

IVs - Independent Variables

LiDAR - Light Detection and Ranging

LOD - Level of Details

MR - Mixed Reality (Sometimes XR)

QR-codes - Quick Response Code. Matrix barcode provides a two-dimensional barcode

RMS - Root-Mean-Square

S.W - Software

SfM-MVS - Structure from Motion - Multi-View Stereo

SHP - Shape file format

TLS - Terrestrial Laser Scanning

TPS - Total Positioning Station

UNESCO - United Nations Organization of Education, Science and Culture

URLs - Acronym for Uniform Resource Locator and an Internet address to a resource

USGS - United States Geological Survey

VR - Virtual Reality

Chapter 1 : Introduction

This chapter introduces the problem statement and presents the research questions and objectives of the research. The chosen case study is the Jeddah Historic Site. The research's scope is addressed while ending this part with the suggested organization of the research.

1.1 Historic Monuments

Over time, people have admitted the importance of historic monuments since they represent critical protection of the national legacy and cultural identity. Many attempts have been made to define the term "historic monuments." UNESCO (1968) defined this term as cultural property to include both movable and immovable. The scope of heritage was extended to include gardens, landscapes, and the environment at national and regional levels. Though the scope of heritage has recently been accepted around the world to include tangible and intangible as well as environmental elements, the final terminology of "heritage" has not yet been standardized for many reasons. One can refer to the absence of uniformity between countries as it was reinterpreted quite differently in Europe, Australia, New Zealand, Canada, and China (Ahmad, 2006).

However, generally said, historic monuments reflect heritage while having endless roles in society, such as the region's history and citizens' identity, along with being a cornerstone of the industry of tourism that adds value to the country's national economy and sustainability (Vacca et al., 2018; Osello et al., 2018; Pocobelli et al., 2018; UNESCO, 2018; Gonçalves et al., 2020). Despite the fundamental importance of historic monuments, they are regularly prone to endless challenges, such as vandalism and natural disasters, which lead altogether to the risks of irrevocable damages and loss of them forever (Paolini et al., 2012; Alitany, 2014; Baik et al., 2015; Chiabrando et al., 2016; Chiabrando et al., 2017; Sammartano et al., 2023). “Jeddah Historic Site” is one of these global places that are encountering these challenges, and the concerned researchers and experts are still calling for urgent solutions (Ibrahim, 2018).

To provide context for the thesis, the work has been done from the point of view of the architect and based on the experience of the author of this study. Using Historical Geographic Information Systems (HGIS) and Historical Information Modelling (HBIM) together, a methodology towards conservation of historic sites is proposed. This approach is especially relevant to the particular challenges peculiar to Jeddah sites. This study presents a methodological framework that connects with HBIM and HGIS data to offer a full solution for conserving and documenting historical data.

1.2 The Chosen Case Study (Jeddah Historic Site) for the Research

The Kingdom of Saudi Arabia (KSA) is blessed with a lot of copious historic monuments and sites that attracted global tourists, such as the historic district of Jeddah City, which has been chosen as a case study for many factors, such as its architectural value, size, and accessibility. The historic area of Jeddah, "Al-Balad," located on the Red Sea’s eastern shore, was founded during the seventh century to serve significantly as a special center of Jeddah. There were such defensive walls in Al-Balad that were torn down during the 1940s, whereas this site is considered a cornerstone to be one of the most cosmopolitan and thriving neighborhoods of the Arab World.

Besides, as considered by De Pint (2005), Al-Balad is an extremely lovely blend of the classic and modern, whereas one can figure out that the glass facades of the modern skyscrapers rub shoulders with the historic buildings distinguished by distinct horizontally embedded wooden beams, which have significantly come to distinguish and symbolize the area over the years. Historically, Jeddah has acted as a major port for Indian Ocean trade routes, channeling pilgrims and goods to Makkah city since the 14th century (Figure 1.1).

Figure 1.1: The geographic location of the study area. Google map, 2018

Nowadays, such a valuable historic site of Jeddah has been significantly authorized and recognized by the United Nations Organization of Education, Science & Culture (UNESCO), along with its linked World Heritage Centre in 2014, according to a report by UNESCO (2014).

1.3 Problem background of the Research

Architectural and cultural heritage is considered a significant asset of collective interests made up of inherited tangible as well as intangible attributes that, in turn, can benefit the present and future societies of the communities. Moreover, this can allow the past to be critically commemorated, while the community can become a tourist attraction and, additionally, an important source of commercial and entertainment use (Ahmad, 2006; Bakri et al., 2012; Bagader, 2016; Bahramjerdi et al., 2016). Therefore, cultural and architectural heritage can give specified meaning and direction to the local territories while also being considered something invaluable that is owned by the citizens and can highlight the nation's values as a result of identarian processes (Quintana et al., 2022).

However, the risks and challenges faced by historic heritage are many, such as vandalism that results in tremendous dangers and irrevocable damages and leads to a permanent loss of these valuable historic heritages (Paolini et al., 2012; Alitany, 2014; Baik et al., 2015; Chiabrando et al., 2016; Chiabrando et al., 2017; Sammartano et al., 2023). While admitting such complications, many global countries have passed resolutions concerning their obligation to protect, conserve, and restoratively preserve their historic heritage, which is considered a significant means to manifest local cultural value. Even UNESCO (2018, p. 133) recommended overcoming any challenges: "*to further develop an integrated conservation strategy for the property*, *including systematic Heritage Impact Assessment (HIA) studies."*. However, one should not mix the processes of preservation of historic heritage with the processes of conservation. Historic heritage preservation stands generally for pausing or understanding the resource only at a significant point in time, effectively protecting it from evolution or change (Cano et al., 2013; Vileikis et al., 2017). As to the conservation of the heritage, it concerns the process of managing change. It is planning to focus on the inherited culture and the cultural artifacts of the specified place, object, or structure. The term "conservation" stands for interpretation, assessment, documentation, and most importantly, strategic management, while considering the uniqueness and individuality of the place (Letellier, 2007; Eppich et al., 2012). We focus on this research by using the term "conservation”.

The process of conserving historic monuments globally attracted the interests of experts (Letellier, 2007; Eppich et al., 2012), while many linked definitions, approaches, policies, attitudes, strategies, and schemes have been created and implemented for the sake of heritage sustainability. This is while considering the existence of a noticeable lack of convenient processes, despite a lot of attempts made previously to implement the global principles of the integrated conservation process. The convenient process of conservation should focus on and implement the latest available technical tools. We considered the definition of Letellier (2007) of conserving heritage while paying attention to the following terms: According to Letellier (2007), "heritage information” is the activity and product of recording, documenting, and managing the information of cultural heritage places. It should be not only an integral part of every conservation project but also an activity that continues long after the intervention is completed. Letellier (2007) defined the term “cultural heritage place” as a general term for immovable cultural heritage, such as archaeological sites, single monuments, groups of buildings, historic towns, or cultural landscapes. The term “heritage information” refers to the integrated activities of recording, documentation, and information management, whereas the term “information management” refers to the process of finding, cataloging, storing, and sharing information by making it accessible to potential users now and in the future (Letellier, 2007). “Conservation” is a discipline concerned with the transmission of cultural heritage, with its significant values intact and accessible to the greatest degree possible (Letellier, 2007). “Documentation” is the already existing stock of information. As an activity, it stands for the systematic collection and archiving of records to preserve them for future reference (Letellier, 2007). “Heritage recording” is the graphic and/or photographic capture of information describing the physical configuration, evolution, and condition of a heritage place at known points in time (Letellier, 2007). “Digital heritage recording,” as opposed to hand (or traditional) heritage recording, includes all forms of digital data capture, ranging from photographs to rectified images, CAD to photogrammetry, total stations to 3-D laser scanning, and voice-to-video (Letellier, 2007). All these terms will be used in this research, respectively.

1.4 Problem statement

Cultural heritage faces many challenges to its conservation and effective communication, especially in cities like Jeddah. These obstacles are made worse by the lack of appropriate digital documentation and the constraints of conventional conservation techniques. Even though immersive technologies are becoming more widely acknowledged for their potential in the conservation of cultural heritage, there are still gaps in their actual application, frequently because of manual processes and project scope limitations. Furthermore, the deterioration of Jeddah's traditional buildings highlights the pressing need for creative solutions to support architects and policymakers in implementing digital techniques for heritage conservation.

The research gap in knowledge is that there is no clear framework for integrating HBIM/HGIS and interactive tools. The focus is on a practical, transferable approach using readily available software (COTS). By creating a workflow to integrate diverse data into a single platform for user interaction. This aims to improve data access, user understanding, and spatial experience through portable AR/VR devices. The study explores expanding the model's capabilities for various applications.

1.5 Significance of the Study

Jeddah Historic Site is similarly facing the same challenges to attain conservation and sustainability. Initially, there is an absence of available and easy-to-use digital recording and documentation to support the conservation process, which has negative implications for these valuable monuments. Many researchers have addressed such challenges. According to Al-Gabban (2013), the rapid urbanization of the area and the regular maintenance processes of the urban morphology have resulted in irreversible losses to this heritage site. Besides, the present status of its documentation appeared traditional while lacking the principles of meeting modernization requirements. The available documentation is not georeferenced in high spatial resolution or illustrated in three dimensions. Another challenge is a lack of applications to consider the extensive requirements for recording, documentation, conservation, and tourism (Patias & Santana, 2011; Ibrahim, 2018). Moreover, there is a noticeable absence of the needed digital materials to support conservation, which in turn makes it difficult for the site to preserve its valuable historic status (Al-Gabban, 2013; Alitany, 2014; Baik et al., 2015; Bagader, 2016). Therefore, discussions have arisen on the importance of conserving historic sites. However, few studies have handled these challenges, such as the documentation of the Roshans and historic wooden windows in the historic district of Jeddah City (HDJ) by Alitany (2014) and the study conducted by Baik et al. (2015). Alitany (2014) focused on using a significant method to integrate image-based modeling and computer-aided design (CAD) modeling technologies. The study by Baik et al. (2015) focused on the integration of Jeddah Historical BIM and 3D GIS for the documentation and restoration of historical monuments. UNESCO (2014) specified the challenges faced by the Jeddah historic site, as initially, more data is still needed on whatever has survived there. This, accordingly, will allow us to understand Jeddah's former role and its influence (UNESCO, 2014, p. 6). Due to the lack of proper maintenance and construction processes, many of the site's traditional buildings as well as public spaces are in poor condition. The result is simply endless serious structural challenges that arise from internal partitioning, alterations, poor repair work, and a lack of water drainage infrastructure (UNESCO, 2014). Given the challenges mentioned, we were motivated by finding convenient solutions to support the site's conservation, with a focus on the latest technical tools available. Interactive and immersive technologies have been selected to support the conservation of the historic site of Jeddah with modern tools. This will contribute to the awareness of the public regarding this valuable site while making it easier to obtain information on its unique history. This process, in turn, requires answering significant questions, which will be the focus of this study.

1.6 Motivations

The historic heritage of Jeddah's sites has fundamental benefits for the Kingdom of Saudi Arabia. These benefits include conserving the culture and traditions of the citizens, promoting the tourism industry, and adding value to the economic growth of the Kingdom. This is clear when considering the sites' inclusion in the UNESCO list, due to their fulfillment of all the criteria for historic heritage stated by this global organization. Given that, we can specify many motivations for conducting this project. Initially, the main motivation of this research is to contribute to the heritage information management of the cultural heritage place of Jeddah, focusing on digital heritage recording and information processing to support the conservation process of the historic city of Jeddah. Another motivation was the absence of appropriate digital documentation of the site and the lack of proper maintenance and construction processes, given the deterioration of the poor conditions of the traditional building there. Therefore, this study aims to assist policymakers in the Kingdom and professionals in architecture in finding out the suggested digital methods for the process of heritage conservation.

1.7 Research Questions, Aims, and Objectives

The main question raised by this study is "*How to design and develop an immersive visualization system through technology integration, to assist the process of conservation of the Jeddah Historic Site?".* From the aforesaid question, there are some sub-questions in need of answers.

1- How to increase the context-awareness of the building architectural heritage of Jeddah City and improve the users' spatial experience?

2- How can we design and develop the best adopted interactive and immersive technologies used for this conservation?

3- What are the challenges and limitations of adopting these technologies and how can we mitigate them?

4- What is the contribution of this study to the world of historic heritage and the implications on the conservation of the historic City of Jeddah?

This research's main aim is to use HBIM, HGIS, and interactive technologies to create and implement a workable, transferable strategy for Jeddah's historic conservation. The project intends to create a process that unifies disparate data sources into a single platform by utilizing commercially available off-the-shelf (COTS) software. This would enhance user comprehension, spatial experience, and data accessibility.

The objectives of the study are as follows;

- To increase the context-awareness of the building architectural heritage of Jeddah City and improve the users’ spatial experience.
- To design and develop the best adopted interactive and immersive technologies used for this conservation.
- To find out the challenges and limitations of adopting these technologies and the way by which we can mitigate them.
- To state the contribution of this study to the world of historic heritage and the implications on the conservation of the historic City of Jeddah.

Briefly, the research aims at creating the needed architectural database while increasing awareness, accessibility to information, and sensitivity towards protecting and conserving this historic district. This study will emphasize the process of integrating a diversity of data sources along with different geo-informatics and the latest computer techniques.

1.8 Methodology

The methodology consists of various but compatible and integrated techniques and methods covering both theoretical and practical studies. Using historical research techniques, by collecting data about the geomatics tools to play major roles in the management of the spatial data, Architecture Engineering Construction (AEC) domain, and BIM. Since BIM supports more intelligent approaches to planning, constructing, and maintaining heritage buildings, there was a critical need to integrate both BIM and landscape geoinformation. With a focus on the gained benefits from the latest technological tools and sensory systems, there will be endless creative methods, by which these historic heritages can be reconstructed digitally and documented for future generations (Böhler & Marbs, 2004; De Laat & Van Berlo, 2011; Dore & Murphy, 2012; Choi, et al., 2015; Albourae et al., 2017; Albourae & Armenakis, 2017; Vileikis et al., 2023).

An analytical research approach used to collect, analyze, and evaluate data in order to make decisions and draw findings. Additionally, the quality and intent of the documents have been assessed using the document analysis research methodology. Settling upon that, the chosen methodology focuses on proposing an integrated approach for establishing the architectural building database of the Jeddah Heritage Site. By recording, extracting all components and features from the outside, and offering a digital resource to aid in the process of comprehending the complete developmental phases of the elements, the goal is to establish an architectural library of 3D historic element models with the greatest geometrical accuracy. This approach can be digitally replicated and then engaged with in both immersive and non-immersive environments, utilizing Geographic Information Systems (GIS) and Building Information Modelling (BIM) to investigate historic structures. Enhancing accessibility to knowledge, awareness, and sensitivity about the preservation and protection of this historic region is the aim.

The causal-comparative research method has been used to identify cause-and-effect relationships between independent and dependent variables. Prospective Comparative Research, this style of casual research has been used to measure the efficiency of merging and integrating technologies, heterogeneous datasets, and BIM/GIS, whereas a conceptual approach will be provided, and a new strategy will be proposed to integrate them into one platform to allow the process of interaction. This study does not aim at developing any kind of software for such integration by any means. Therefore, in this study, commercial off-the-Shelf (COTS) application software has been used to demonstrate the feasibility of the proposed methodology. This research aims to make novel conceptual contributions that will be validated later by measuring their influence during the phases of implementation.

Supporting the conservation process is one of the main aims of this study. In this context, an application for an immersive 3D environment has to be created with diverse levels of details and links to contextual information, where the final output will have multiple facets. The developed model will be used for the proposed applications, which will be required to feed the models into interactive visualization platforms. The collected historical and architectural information will be useful for documentation, conservation, and tourism purposes, given their benefits and objectives. The process of documentation is linked to cutting down on duplicative work, which is an essential element of quality and process control. Documenting the heritage monuments' information aims to describe the use, maintenance, operation, or even design of the software through the use of listings, manuals, and diagrams (Mbaiwa & Stronza, 2011; Lemos et al., 2012; Mangubhai et al., 2020). Moreover, conservation is linked to the process of helping to ensure the objects' longevity, which has value for their contents; therefore, information can be easily learned from them as artifacts. Finally, tourism purposes aim at illustrating the country's economic status, political progress, and cultural habits of citizens through exploring their historic architecture (Mbaiwa & Stronza, 2011; Lemos et al., 2012; Mangubhai et al., 2020).

Finally, the analytical analysis method and document research method have been used by analyzing. The capabilities of the currently available augmented and virtual reality (AVR) tools will be used and blended in an integrated way, allowing the users to virtually experience and interact with the site from remote locations. The work is based on 3D architectural elements of the nominated site to understand the evolution of the architectural heritage of the city. The integrated

HBIM/HGIS model will be uploaded to a cloud-based server and stored as a library, which can be shared over URL links while using cloud streaming to publish historical information for an interactive user experience. These 3D models will also be helpful for possible future applications, such as the physical reconstruction of degraded monuments, gaming designs, and educational purposes.

While some of the previous studies were based either on the integration of BIM and GIS or on HBIM only to document the heritages, this present study proposes a new fully integrated approach between HBIM and GIS that differentiates this study from the previous ones.

The integrated approach of this study consists of three main parts:

Part I: HBIM and HGIS generation from originally collected field data, such as the Jeddah historical databases by the Author;

Part II: Integration of HBIM and HGIS;

Part III: Interactive user experience environment.

Consequently, it is expected that the results can help the process of conserving the Jeddah Historic Site.

1.9 Scope of the work

The parameters that will govern the thesis's operation are referred to as the dissertation's scope. In order to preserve Jeddah, Saudi Arabia's historic legacy, the task entails implementing an integrated Historic Building Information Modelling (HBIM) and Historic Geographic Information System (HGIS). using improved context-awareness of the historic site, increased accessibility to digital data, and an improved spatial experience for users using portable and augmented reality (AR) and virtual reality (VR) devices, the project seeks to give a novel way to help the conservation process. Various geospatial vector layers must be integrated, data must be re-projected and corrected, buildings must be categorized according to their historic and architectural significance, and point clouds must be converted into 2D HGIS models.

The work's scope includes integrating different CAD data, 2D HGIS models, and geographic vector layers to support the conservation of Jeddah's historic site in the Kingdom of Saudi Arabia. The process involves identifying historic structures according to their significance and re-projecting, correcting, and aligning various data layers to a common reference system. In addition, creating georeferenced point cloud data, fusing BIM and GIS functionalities, and creating an interactive UX environment with immersive technologies like VR, AR, and MR are all part of the job.

1.10 Contribution of the Study

The study contributes specifically to Saudi Arabia's heritage documentation practice and integration of digital technologies towards conserving these fundamental sites, while bridging the recent architectural heritage knowledge gaps and providing another perspective on a new way by which conserving the historic heritage should be conducted by making the designs and concepts of the architectural heritage elements easier to understand.

Another contribution is offering new methods and strategies for the heritage information management of the Jeddah Historic Sites of the Kingdom of Saudi Arabia. Therefore, this study provides the audience, such as historians and architects, with the suggested new methodological approach for adopting the new technologies easily, which are accurate, inexpensive, and a practical solution for surveying, recording, reconstructing, and documenting the elements of the historic heritage.

Another major contribution of this study is participating in the national effort for better documentation and conservation of the Jeddah Historic Site. The study will therefore be useful in assisting the projects of many professionals who are working in the conservation area with different backgrounds (architects, engineers, historians, restorers, archaeologists, and researchers, among others) and in academic fields, providing educational materials for students and teachers to transmit this architectural knowledge to future generations. Another contribution is to involve citizens in the conservation processes based on the distributed digital heritage information, especially the 3D model of heritage buildings.

In short, this study will help create an educational resource for researchers and students of architecture, history, and culture while motivating different sectors of society to use and interact with the integrated data for the historic area. They can use the suggested model to query the historical model and extract the information they need. For example, an architect using this new development platform can extract all the information needed in case a renovation is needed, visualize with all the details (height, width, material, and spaces) the area and its surroundings, prepare cost estimates for the renovation of heritage, and provide a plan to geo-design it.

The study can answer the stated research questions and go beyond mere technical contribution. It contributes to both conservation and heritage building and distributes the tangible and intangible heritage and legacy of Saudi historic city buildings and sites. At this point and based on the expected outcomes, the study’s contribution can include contributing to an appropriate conservation approach to the historic buildings in the city and to making sustainable decisions in urban planning and sprawl control.

Such contributions are linked to the most important objective of this research, which is to design and develop an immersive visualization system through technology integration by using commercial off-the-shelf (COTS) software components specifically for HGIS and HBIM and for the virtual interact to reconstruct the architectural heritage site, increase its digital accessibility, interact with it, increase contextual awareness, and introduce an immersive environment to enhance users experience and serve as cultural heritage documentation of the historic district of Jeddah (HDJ), The Kingdom of Saudi Arabia.

The integration of interactive and immersive technologies with HBIM and HGIS technologies on a single platform is the study's main scientific and technical contribution. Through the use of portable, augmented reality (AR) and virtual reality (VR) devices, this integration seeks to improve context awareness of the site, boost accessibility to digital data, and improve the conservation process of the historic site of Jeddah. It also aims to improve users' spatial experience. The study's results are anticipated to improve context knowledge of Jeddah's architectural history and offer users interactive experiences that close the gap between the needs of tourists and the tourism sector by leveraging the most recent technologies. The study also intends to establish a thorough reference database for upcoming historical conservation initiatives, stressing the significance of implementing these.

1.11 The Organization of the Research

- ❖ Chapter 1: Introduction: this chapter explains the main points of the entire study, which will be detailed in the following chapters.
- ❖ Chapter 2: Heritage Conservation - The Historic City of Jeddah
- ❖ Chapter 3: Literature Review and Related Works: This chapter reviews the state-of-the-art cultural and historic heritage recording and documentation, cultural heritage information management, and interactive and immersive technologies that were being utilized by some similar case studies.
- ❖ Chapter 4: HBIM and HGIS Generation. This chapter will discuss the process of generating HBIM and HGIS to pave the road towards the following chapter of integrating HBIM and HGIS.
- ❖ Chapter 5: HBIM and HGIS Integration: This chapter will include concepts, architecture, modeling, requirements, and issues of the HBIM and HGIS integration.
- ❖ Chapter 6: Visualization - Interactive User Environment
- ❖ Chapter 7: Conclusion, Recommendations, and Future Work: this chapter summarizes the achievements that have been made in this study, and sheds light on the novelty and contribution of the study, along with the potential future research direction.

Figure 1.2 illustrates the organization of the study.

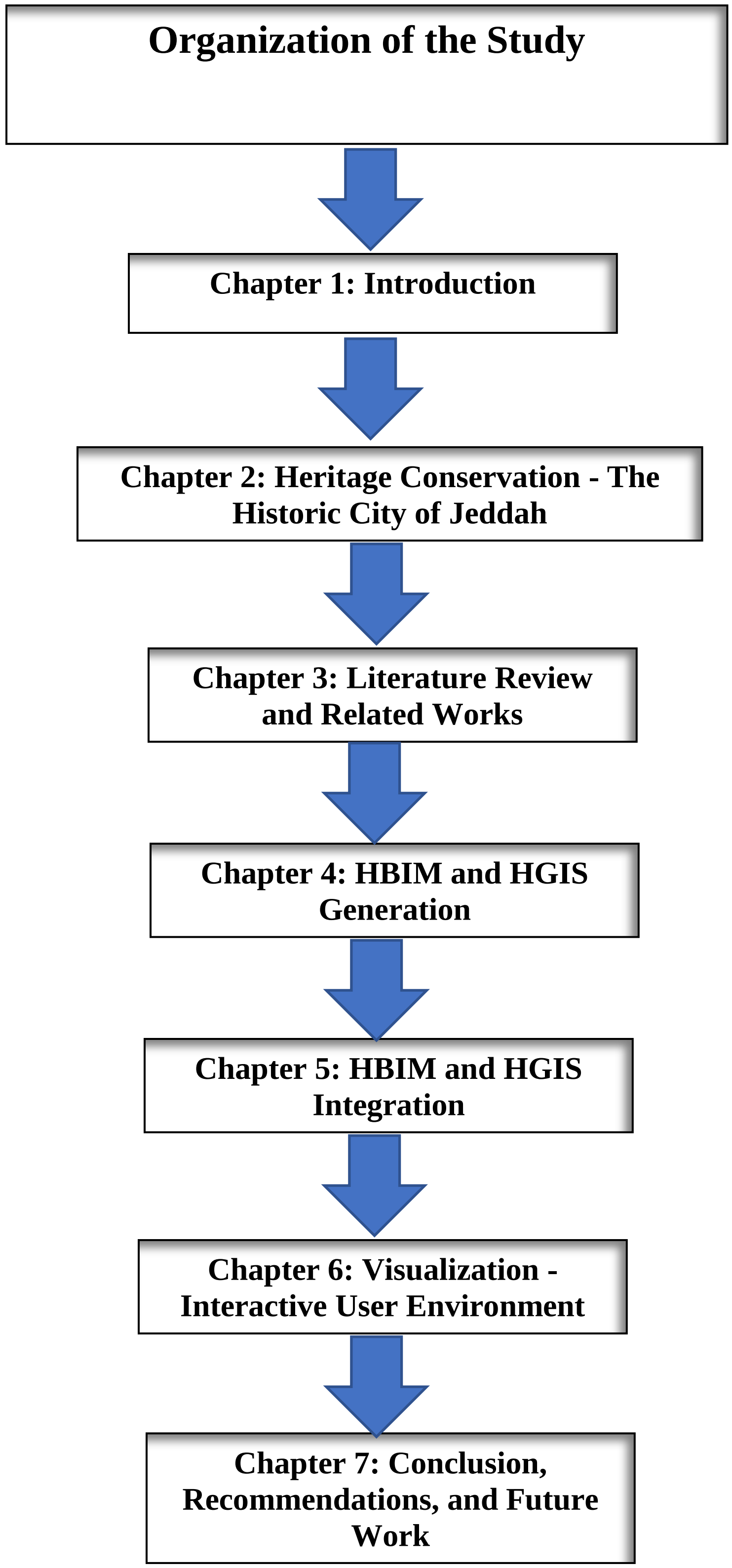

Figure 1.2: The Organization of The Study

1.12 Summary

This chapter articulated an in-depth clarification of the aimed study while stating the study's problem statement and concept of the research; the chosen case study (Jeddah Historic Site); the problem statement; the research questions; the aim and objectives of the study; the suggested research methods; the scope of the research; and finally, the organization of the suggested full project. The next parts will specify the details of the aforesaid items in separate chapters.

Chapter 2 : Heritage Conservation - The Historic City of Jeddah

2.1 Introduction

The chapter addresses the historic city of Jeddah, its geographical and architectural values, elements of buildings, its inclusion in UNESCO, and the justifications for its need for systematic conservation while discussing historic heritage conservation.

2.2 Historic City of Jeddah's Geographical and Architectural Values

Geographically, Jeddah city is located significantly on the Red Sea's Eastern Shore, approximately halfway between the Kingdom of Saudi Arabia's northern and southern borders. The Arabian Peninsula's western coastline on the Red Sea appears to be a narrow coastal plain that is commonly known as Tihama, whereas such a narrow coastal strip is rising steeply to shape the Hijaz Mountains.

The Hejaz area is located on the Red Sea, almost on the western side of the peninsula, while also including important centers and cities of trading in the country, including Madinah, Makkah, Taif, and Jeddah. There is a continuous line of significant foothills, outliers of the Arabian Massif, that backs Jeddah city and the Tihama coastal plain to the east. Jeddah's existence is related to a gap in the natural barriers, which permits communication between the coast and Makkah effortlessly, considering another specified gap in coral reefs fringing the shore of the Red Sea (Angawi, 1995). Figure 2.1 illustrates the geographic location of the historic city of Jeddah.

Figure 2.1: The geographic location of the historic city of Jeddah - Source: (Alitany, 2014)

Traditionally, the initial human settlement in the Jeddah area dates from the second century B.C., in particular, when the Quda'a, an old tribe that came from Yemen, settled there. During the sixth century, Persians settled in Jeddah while they were building the former walls around the city and establishing the harbor as a tremendous point of trading. In the siege cases, many cisterns and wells were significantly dug and established around and inside the city to supply regular water and increase the resilience of Jeddah (Pesce, 1976).

Firmly said, Jeddah was playing its major role as an important seaport during the seventh century A.D. when the city was seized by the Arabs. During the year 646, and according to the request of the Makkah's people, the old landing of Shuaybah, located in Jeddah's south, was abandoned by the Caliph in favor of Jeddah, which in turn became the critical port of Makkah and started receiving regular pilgrims who were coming to Makkah by sea (Pesce, 1976).

Consequently, Jeddah, as an initial focus of Islam, became an active center of trading while channeling many supplies coming from South Arabia, the western shore of the Red Sea, Egypt, and India to this holy spot (Pesce, 1976).

The prosperity of Jeddah focused on its fundamental role as an exclusive Red Sea entry, in particular, between Egypt and India. Due to the changing currents and winds and the coral reefs, navigation on the upper side of the Red Sea was limited for ships that were coming from parts of the Far East.

Indeed, Jeddah's historic success was because of its significant symbolic collaboration with the Makkah Holy City and its unique geographical location at the monsoon-dominated area edge.

From the initial period of the 19th century, Jeddah started to receive major diplomatic representatives from Europe, which was called "Balad Al-Kanasil." From 1918, there were significant battles between the Saudi forces and Sharifian until Abdulaziz Bin Saudi could lay siege on this city while conquering Jeddah (on December 23, 1925). Most noticeably, this date is recently considered a celebrated day as the national holiday. Bin Saud spent the following years powering his position and settling the internal and external challenges, whereas he finally, in 1932, proclaimed his realm to be known as "The Kingdom of Saudi Arabia," and he became the former king. Such unification of the Najd and Hejaz regions has resulted in an increase in the region's stability and an increase in pilgrims to the Holy City through the city of Jeddah.

The historic city of Jeddah had developed significantly for many centuries, in particular within its protective walls, which were considered the most conspicuous features that made a lasting impression on individuals who used to approach it. Jeddah had its gates, which opened on each side, whereas on the northern side, Bab Al-Madinah was significantly doubled by Bab Al-Jadid and was opening to allow the entry of cars; on the eastern side, there was Bab Makka, whereas a road departed for the Holy City; and on the southern side, there was Bab Al-Sharif, Bab Al-Bunt, and Bab Al-Magharibah, as illustrated in Figure 2.2. However, such historic gates are defined architecturally as the old Jeddah (Telmesani et al., 2009).

Figure 2.2: Outside of Makkah Gate - Source: (Pesce, 1976)

Those gates are correlated, leading to the inner parts of the old Jeddah's four urban quarters: Ha'rat Al Sham and Ha'rat Al Mazloom to the northern part of Ha'rat Al-Yaman, as well as Ha'rat Al-Bahar up to the southern part to be the tremendous pedestrian thoroughfares. Given that these gates are not significantly separated, they are alternatively divided for orientation and administrative reasons (Telmesani et al., 2009). However, one can figure out a semi-private Ha'ra that was considered a natural extension of the related family and created social unity and full integrity. Hence, the matter needs to clarify that the privacy, safety, and well-being of the residents of Ha'ra were critical, as was the responsibility of the community's members, not only as a well-described gesture but also as a religious obligation (Telmesani et al., 2009). There is Souk Al Alawi, which is known as the basic east-west axis and links Bab Al Bont, the western side of Ha'rat Al Bahr, with Ha'rat Al Sham's Bab Al Madinah significantly, towards the southern part, and branches out into the narrow alleys that link, finally, the Bab Al Shareef in the southern part (Figure 2.3).

Figure 2.3: Gable Street, which leads to Souk Al Alawi - Source: (Telmesani, et al., 2009)

Along with the residential areas, one can observe the social unity that is characterized by the urban quarter's life as well as its spatial organization and, additionally, the elements of hierarchical urban. According to Telmesani et al. (2009), those involve dense organic urban fabric to preserve the entrances' privacy, narrowing the residential alleys and the pathways oriented for taking advantage of the shade of the buildings to provide access with significant thermal relief that helps in making the temperature of summer bearable and acceptable, while opening small squares and creating special places for interacting socially. They are located around the local mosques and prominent homes of families (Figure 2.4).

Figure 2.4: The Dense Fabric of the Historical City of Jeddah - Source: (Al-Gabban, 2013)

However, generally, with such stabilization of the revealed political status and the enjoyed peace under King Abdulaziz's reign, the increased trading and numbers of Pilgrims, along with the oil revenues, significantly increased and lasted the influence of Jeddah's prosperity. The city started expanding its walls, ceased to play its specified historic role, and became obsolete quickly. On the other hand, the city's wall demolition was decided and implemented to favor urban growth (Angawi, 1995).

Settling upon that, recently, the historic city of Jeddah represents such a small area, just covering around one $km^{2,}$ and is considered a major entity within the greater Jeddah, approximately $1/100^{th}$ of its entire population (Figure 2.5). Notwithstanding, the major modifications have taken their places in particular within this part's original fabric and the surrounding seascape.

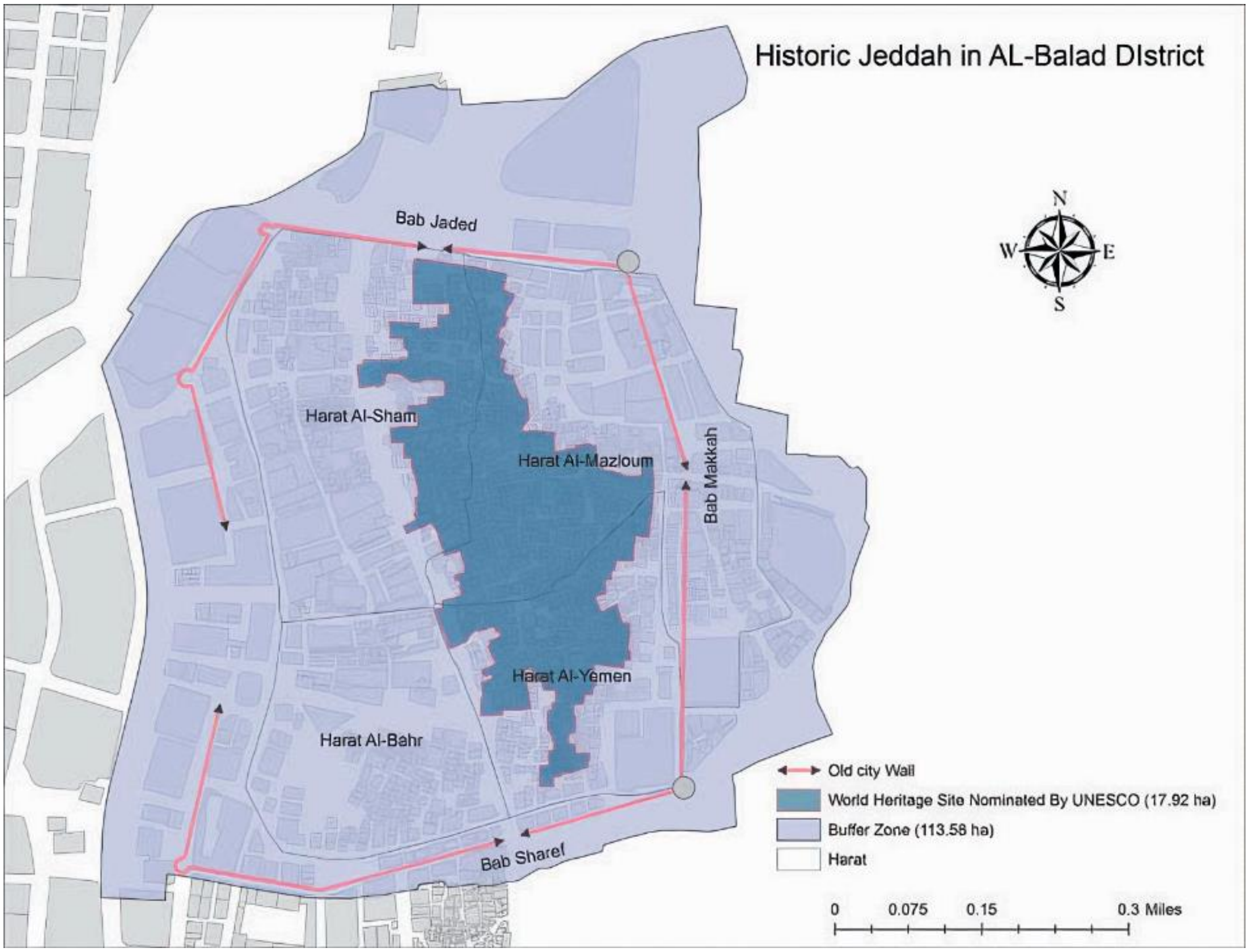

Figure 2.5: The Historic City of Jeddah - Source: (Sahahiri, 2019)

However, Al-Balad still maintains a significant, coherent unity and a certain character of urbanism. Moreover, the entire area that was used to be included within the walls, though partially reconstructed with special modern buildings, retains its original network of streets while preserving its nature and being easily recognized.

2.3 Historic City of Jeddah's Elements of Buildings

Over time, particular multi-stored residential homes appeared with the most characteristic elements of Jeddah while providing the needed spaces for families. Generally said, in the Kingdom of Saudi Arabia, similar to the region of Hejaz, one can observe that the local traditions and culture are profoundly impacted by the rules of Islam (Pesce, 1976). Indeed, Islam is not just a religion; it is a way of life for Muslims, whereas the community, the culture, and the organization of the community are directly impacted by Islam. These elements are reflected in the planning and designing of the cities, along with the specified traditional architecture of the buildings.

In Jeddah's traditional buildings (Figure 2.6), one of such principles is seen in the design of the historic domestic architecture, which could reflect the major importance of preserving the females' privacy at home. To shed light on these facts, one can observe, for example, those windows that were positioned generally above the level of streets, roof terraces that were created in such secluded places while being surrounded by so many balustrades, to provide the needed privacy for homeowners, especially females, whereas the males' guests were significantly entertained in the reception places that were isolated from the other building's areas, therefore the homeowners could host their guests free of disturbing the family's females (Pesce, 1976).

The materials used in the construction of old Jeddah's historic buildings consisted of limestone brought from the sea, which was called Mangabi stones. As to the structure, it included load-bearing walls as well as hardwood flooring. Most of those buildings were five stories high. Moreover, based on the climatic aspects, such heights of the buildings in old Jeddah offered special shades to those narrowed alleys that cooled the buildings' internal sides.

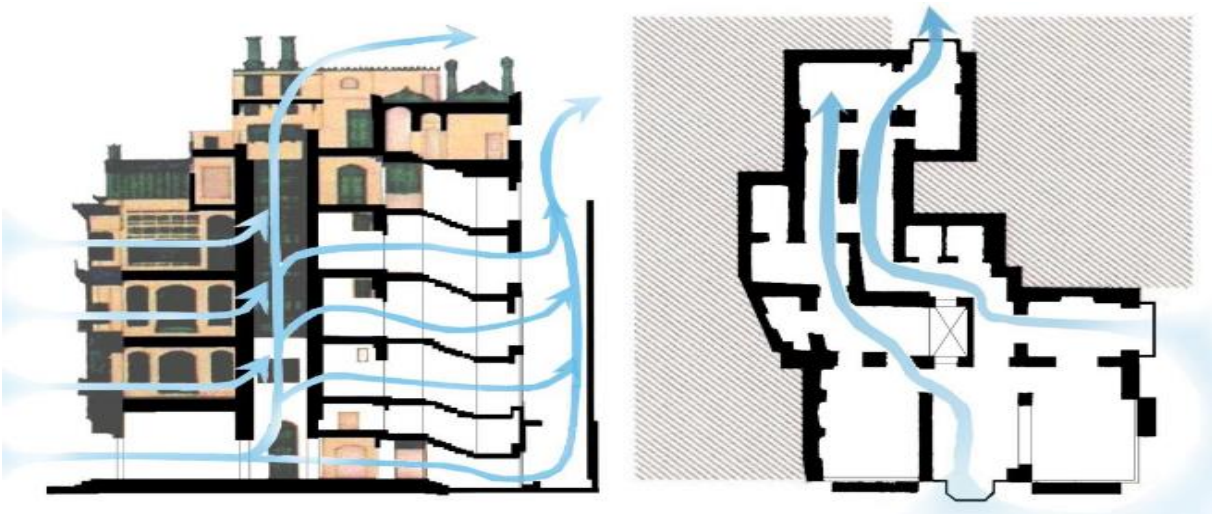

Figure 2.6: Typical Houses of Historic City of Jeddah - Source: (Pesce, 1976)

The architectural significance of Jeddah's historical city’s houses is characterized by special decoration on plaster and wood, whereas doors, windows, and Roshan are decorated with the most wonderful types of decoration (Figure 2.7).

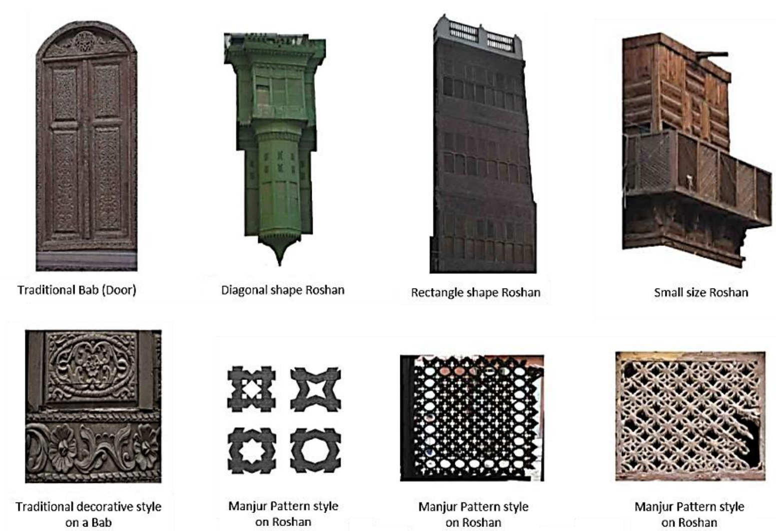

Figure 2.7: Traditional architectural elements in Jeddah historical city (Sahahiri, 2019)

2.4 Historic City of Jeddah's Inclusion in UNESCO

Many attempts have been made to include Jeddah's historic site in UNESCO's World Heritage List (WHL), particularly by the Saudi Commission for Tourism and Antiquities (SCTA), that have been successful (Ibrahim, 2018). For the Jeddah Historic District to be recognized significantly by UNESCO and meet the needed criteria, the Historic Area Preservation Department (HAPD) was founded in 1990 to promote the cultural tourism of Saudi Arabia.

Nasseef House, which is located in Al Balad, has been recognized by UNESCO, and it was described by the organization as a famous historic building. However, Nasseef House is considered a historic museum as well as a cultural center, with special lectures and exhibits shown and offered by historians (Figure 2.8).

Figure 2.8: Nasseef House - Source: (UNESCO, 2014)

Being included in UNESCO’s World Heritage List (WHL), those historic sites in Saudi Arabia became competitive with other world heritage properties’ files, which in turn are considered evidence of the distinguishing characteristics while deserving to be qualified to be selected as the most distinct searched by UNESCO to be included in its list (Ibrahim, 2018).

Recently, this historic site of Jeddah was recognized by the United Nations Organization of Education, Science, and Culture (UNESCO) and its World Heritage Centre in 2014 (UNESCO, 2014). This is with a focus on the UNESCO criteria. The UNESCO criteria reflect the major role played by this organization, which aims to encourage the identification, protection, and conservation of natural and cultural heritage globally while considering it to be of tremendous value to humanity (UNESCO, 2014). Given that, the Jeddah Historic District has the qualifications and characteristics that facilitate the process of fulfilling the UNESCO criteria.

2.5 Justification of Jeddah City’s Needs for Systematic Conservation

Despite the inclusion of the historic city of Jeddah in the UNESCO list, one can still figure out many challenges faced by this site. Many challenges may be due to natural disasters, such as floods, pollution, poaching, and the process of uncontrolled urbanization. The lack of proper documentation on the site is the most critical challenge (De Pint, 2005; Al-Gabban, 2013; Alitany, 2014; Baik et al., 2015; Bagader, 2016).

This is because the increasing interest in this site’s cultural heritage protection needs enhancement of the traditional methods in its documentation, along with a wider participation of the academic disciplines. However, in the process of transmitting such cultural heritage to the next generation, one should pay attention to the process of preparing the measured drawing and reconstruction model, along with the documentation's accuracy (De Pint, 2005; Al-Gabban, 2013; Alitany, 2014; Baik et al., 2015; Bagader, 2016).

Given that, recent technology and the digital techniques of conservation make it possible to record the overall buildings, which are not reachable by the aforementioned traditional methods of documentation. The Jeddah site requires digital documentation for its historic heritage conservation and sustainability.

2.6 Historic Heritage Conservation

Generally speaking, "historic heritage" refers to the places of significance to individuals on account of their historic physical, such as technological, architectural, archaeological, and cultural values. Many attempts have been made by experts to define the term "historic/cultural heritage" (Marsden, 1992; Blöndal, 2003; Haddad & Akasheh, 2005; Letellier, 2007; Patias & Santana, 2011; Paolini et al., 2012). South Australia's Heritage Branch defined historic heritage as a study that focuses on significant aspects of the past to keep them (Marsden, 1992). This definition is narrow, but there is still a need to broaden it further. Following the definition of Saidatulakmal & Fernandez (2011), the term could include historic bridges, stones, mansions, monuments, worship places, and war relics. UNESCO indicated this term as its inclusion of both tangible and intangible categories, whereas tangible cultural heritage included both movable and immovable heritage. The immovable heritage involved monuments, historic buildings, and archeological sites. This definition concentrates on artifacts, sites, buildings, traditions, and literature.

Accordingly, one can conclude that the historic heritage is seen as a scope of the area while looking at the civilization's origins, evolution, and/or the interpretation one makes of the past while involving archival materials, natural heritage, cultural heritage, and built heritage. Undoubtedly, historical heritage has benefits for individuals, communities, and the country as a whole.

Historic and cultural heritage is significantly important for shaping the country’s national identity, in that the national identity is often shaped with a focus on heritage sites, structures, and monuments that can play major roles in differentiating the society from others globally (Bakri et al., 2012; Al-Gabban, 2013; Brumana et al., 2013; Cirulis et al., 2015; Economou, 2015; Bagader, 2016). These heritage sites can act as a specified bridge between the past and the present and offer attractive landmarks while attracting foreign tourists and promoting the economy of the country (Del et al., 2020). Given the definitions and importance of cultural heritage, one can admit the existence of many issues and challenges beyond the historic sites’ survival.

Numerous factors threaten the historic heritage. Broadly speaking, there are the threats of armed conflicts and wars, the threats of earthquakes and other sudden natural disasters, poaching, pollution, the process of uncontrolled urbanization, and most importantly, unchecked tourist development that can pose serious challenges to these sites (Vileikis et al., 2017; Elbaz et al., 2019; Del et al., 2020; Gonçalves et al., 2020; Khalil et al., 2020; Ozturk & Ozen, 2020). Critically, the historic site of Jeddah is facing most of the aforementioned problems, adding to the lack of a digitalization process for conserving these valuable sites. Due to these serious facts, mitigation is highly recommended to conserve these sites.

While proceeding with the concept of historic heritage mitigation, one can pay attention to two main terms used in such mitigation: “preservation” and "conservation." Preservation stands for pausing or understanding a significant resource only at a specified point in time while effectively protecting it from evolution or change. However, such a term pigeonholes historic structures, since people who do not comprehend or even embrace preservation are often intimidated by it. On the other hand, the term “conservation” concerns the process of managing change. It is considered a plan focusing on the inherited culture as well as the cultural artifacts of the place, object, or structure. It means interpretation, assessment, documentation, conservation, and strategic management. In addition, “conservation” considers the uniqueness and individuality of the place or even a collection object (Vileikis et al., 2017; Elbaz et al., 2019; Del et al., 2020; Gonçalves et al., 2020; Khalil et al., 2020; Ozturk & Ozen, 2020). As mentioned by Bakri et al. (2012), the process of conserving historic heritage can be considered critical for the country’s sustainability. This is in line with the fact that the process of conservation stands for maintenance and protection. The historic site’s conservation reflects the process of conserving valuable architectural values. In this presented study, we adopted the process of "conservation”.

Historically, heritage conservation and documentation relied on human interpretation, such as hand drawings, on-site measurements, sculptures, and pictures, which consumed time and effort while leading to the significant misspelling of facts (Millard, 2012). With modern attitudes toward the conservation of heritage sites and monuments, the adoption of new technologies can support monitoring the unavoidable degradation of sites due to negligence, natural disasters, or traumatic events such as war (Haddad & Akasheh, 2005; Letellier, 2007; Eppich et al., 2012). In line with this, with the rapid change in information technology and the evolution of architectural visualization from traditional paper drawings to screen displaying to virtual reconstruction in 3D, new forms of digital representation can be better for understanding the visual, facilitating dialog and communication, and fostering engagement through interaction within a scene (Vileikis et al., 2017; Elbaz et al., 2019; Del et al., 2020; Gonçalves et al., 2020; Khalil et al., 2020; Ozturk & Ozen, 2020). Figure 2.9 shows the evolution of architectural visualization in heritage documentation.

The information in this dissertation's Chapter 2 is significant since it gives readers a crucial overview of Jeddah's historical background. The introduction to the historic city, its geographical and architectural significance, and its UNESCO designation are covered in detail in Sections 2.1, 2.2, and 2.4.

Comprehending this information is crucial in order to appreciate the author's composition, since it establishes the background and importance of the ancient city of Jeddah. It makes it easier for the reader to comprehend the significance of this city's conservation and the reasons the author's research is focused on it. It also serves as a starting point for the discussions and analyses that follow in this dissertation.

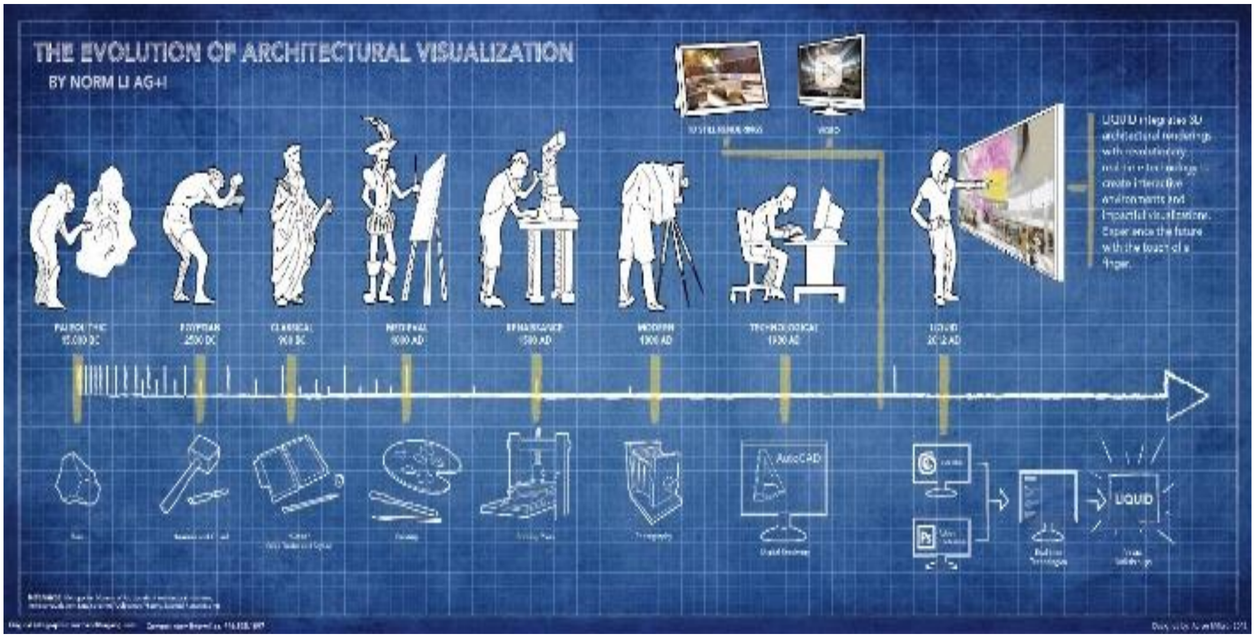

Figure 2.9: The Evolution of the Architectural Visualization (Millard, 2012)

Many techniques have been adopted by previous researchers in the process of conserving cultural heritage as an attempt to mitigate the drawbacks of hand documentation. These attempts reflect the fundamental transfer from traditional methods of conservation to digitalized ones and will be outlined in the following chapters.

2.7 Summary

The value of the architecture of a building is admittedly a most comprehensive and descriptive concept that is governed by engineering, technicians, and economists to reach the most appropriate exploitation of the architectural works. This can add value to the human environment, the culture of societies, and the welfare of countries, too.

This chapter briefly discussed the basic facts concerning the historic city of Jeddah. There were references to the city's architectural values, elements of buildings, and its inclusion in

UNESCO. The following sections discussed the justification of the historic city's needs for systematic conservation while referring to the process of historic heritage conservation, considering that the city has fulfilled all the criteria stated by this global organization.

Chapter 3 : Literature Review and Related Works

3.1 Introduction

This chapter is specified to explore and discuss the previous research conducted in literature by other authors, who handled similar topics, respectively.

3.2 Digitalization of Historic Heritage Documentation

With the rapid change in information technology and the new technical methods of communication, the digitalization of documents related to historic heritage has become a fundamental need for ideal conservation. According to a study conducted by Economou (2015), our recent attitudes towards historic heritage were critically changing due to the expansion of the included digital media, whereas our engagement with the process of conserving these valuable sites became through many channels of the digital surrogates. In line with this concern, the social interactions at the sites and most of the heritage discussions were transferred to the recent digital sphere (Vileikis et al., 2017; Elbaz et al., 2019; Del et al., 2020; Gonçalves et al., 2020; Khalil et al., 2020; Ozturk & Ozen, 2020; Baik et al., 2021; Vileikis et al., 2023).

Additionally, one can refer to the growing exploration of the historic site's potential by heritage organizations and professionals. On the other hand, besides employing the new information technology for capturing data and managing the sites, many cultural institutions were additionally experimenting with digital media to communicate easily according to the new attitudes and attract new audiences. Still, one can admit that not only did digital technologies impact the understanding and management of historic heritage, but also other wider heritage interpretations impacted how such digital methods were being used.

3.3 Digital Recording of Historic Heritage

Most of the existing studies in the literature handled the process of conserving the historic heritage by using specified tools or methods in different ways and on different occasions. However, the common methods used included digital photogrammetry and laser scanning, integrating HBIM/HGIS, and interactive and immersive technologies, either separately or through the selected integration (Dore & Murphy, 2012; Brumana et al., 2013; Chiabrando et al., 2016; Osello et al., 2018; Vacca et al., 2018; Pocobelli et al., 2018; Fadli & AlSaeed, 2019; Andaru et al., 2019; Alshawabkeh et al., 2020; Baik et al., 2021; Lanen et al., 2022; Alshawabkeh et al., 2023). Remondino (2014) summarized the major techniques and their applicability, as illustrated in Figure 3.1.

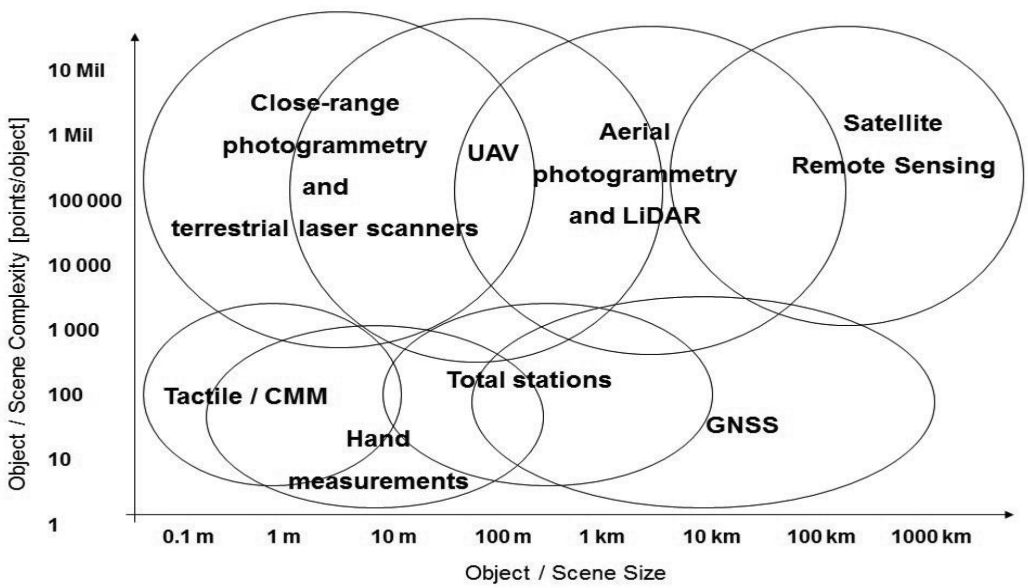

Figure 3.1: Model Reconstruction Methods (Remondino, 2014)

The next sections will illustrate the aforesaid technical tools.

3.3.1 Digital Photogrammetry and Laser Scanning

Digital photogrammetry and laser scanning are the most valuable measurement techniques that have been used recently in heritage documentation because of their ease of implementation and updating, which offer accuracy for acquiring two- or three-dimensional image data and large complex objects (Kadobayashi et al., 2004; Nuttens et al., 2011; Alshawabkeh et al., 2020). For example, PhotoModeler software can be used to extract accurate measurements and three-dimensional models from a set of 2D photographs (Haddad & Akasheh, 2005; Jiang & Miao, 2011; PhotoModeler Tutorial, 2013). Moreover, laser scanners are utilized intensively for the generation of 3D models in many areas, including topographic mapping, land cover classification, and object extraction (Mallet & Bretar, 2009; Yan et al., 2015).

Regarding the positioning information, Leica SmartWorx Viva integrates Total Positioning Station (TPS) and Global Positioning Systems (GPS) technology, which are used as traditional surveying techniques for specifying and positioning the object coordinates. Positioning information in heritage documents is crucial because it provides both outdoor and indoor positioning information while providing accurate position and orientation for document readers (Kuflik et al., 2012).

Close-range photogrammetry is used in digital heritage while measuring objects directly from the digital images taken by a camera at a close range. It has advantages in documentation, such as allowing measuring a specified building or a part of it, in particular very high, dangerous, very low, or very detailed or damaged (Nuttens et al., 2012; Fawzy, 2019). Another advantage is the possibility of using the offered data in the future (Nuttens et al., 2012; Fawzy, 2019). Terrestrial Laser Scanning (TLS) is a ground-based, active imaging method that quickly acquires accurate, dense 3D point clouds of the surfaces of an object by laser range finding. It has advantages in its use in conserving the heritage, such as quality and accuracy compared to other traditional laser scanning methods (Grussenmeyer et al., 2008; Nuttens et al., 2012; Baik et al., 2021). Given that, we need to acquire rich data. Data richness qualifies as having such a large stockpile of data in which there are a lot of pieces of information. Collecting measurement data from multi-sensors can assist in obtaining rich data collection for heritage sites while paying attention to various studies that have demonstrated the use of laser scanning techniques and digital close-range photogrammetry to enhance the quality of the acquired data (Kadobayashi et al., 2004; Nuttens et al., 2011; Remondino, 2011; Andaru et al., 2019; Alshawabkeh et al., 2023). The following (Figures 3.2, 3.3, and 3.4) illustrate the techniques and concepts of close-range photogrammetry, terrestrial laser scanning, and traditional laser scanning.

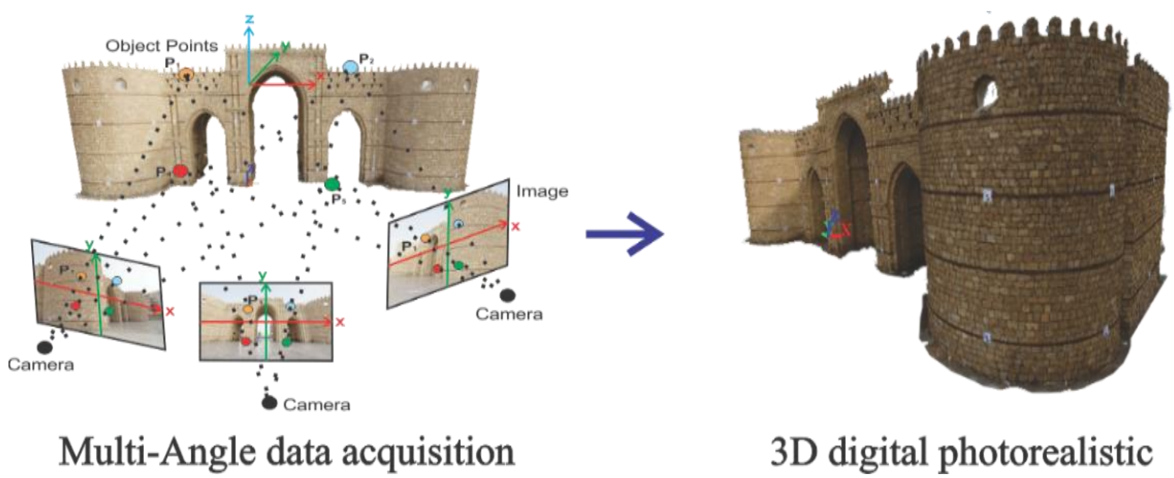

Figure 3.2: Close-Range Photogrammetry

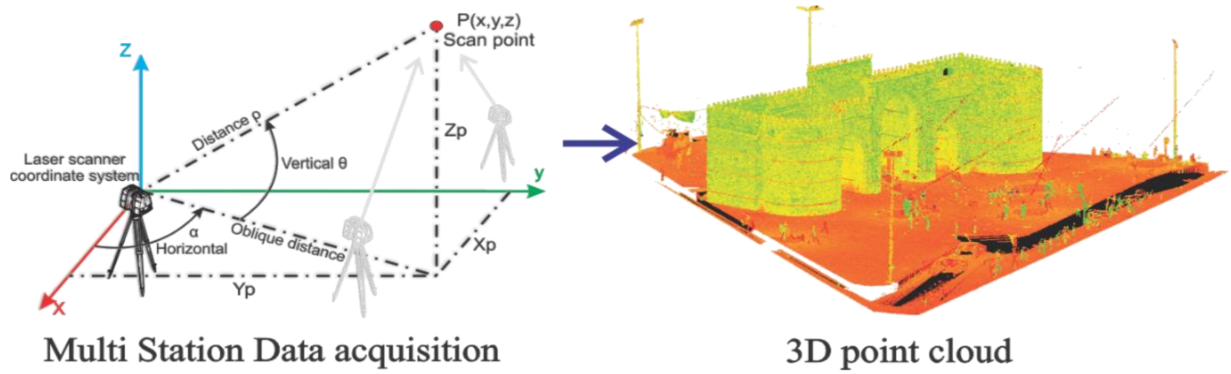

Figure 3.3: Terrestrial Laser Scanning

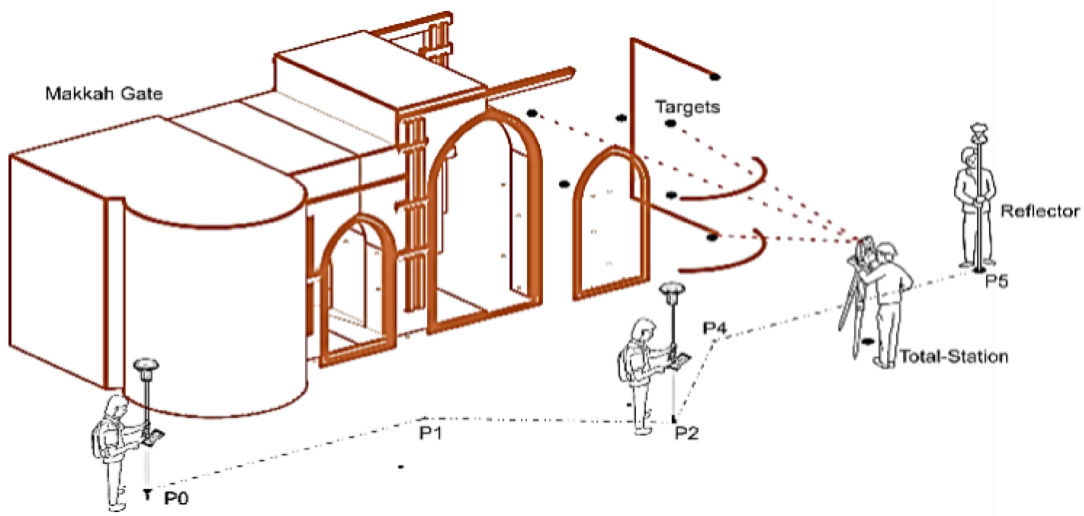

Figure 3.4: Traditional Surveying Techniques

For the 3D-model generation of heritage sites, several techniques for model generation are available that can be used individually or collaboratively (Boehler & Marbs, 2004; Kadobayashi et al., 2004; Grussenmeyer et al., 2008; Remondino, 2014), considering the need to utilize an integrated approach.

Digital documentation is the documentation of a target in digital formats, which provides many benefits, such as capturing the most intricate details of sites and reaching larger audiences. The information obtained with this technology can be utilized in a plethora of interesting applications in the classroom, coaching, or even gaming (Haddad & Akasheh, 2005; Haddad, 2011; Eppich, 2011; Dore & Murphy, 2012; Brumana et al., 2013; Alitany, 2014; Baik et al., 2015; Bitelli et al., 2017; Vileikis et al., 2023).

The digital documentation of the Historic District of Jeddah City (HDJ) generates several challenges because of its construction and the number of details needed to be extracted for creating descriptive models. Due to the large size of the site, modeling using aerial photogrammetry appears to be the natural choice for conservation, though some gaps were detected. Because of the narrow alleys and overhung historic wooden windows (Roshans or Shubak) or any other obstacles that appear in the site (trees, people, wires, etc.), much of the building facades are inaccessible by aerial photogrammetry. Similar reasons may create barriers to data acquisition from ground-based data collection techniques, whereas the roofs and building interiors need to be considered (Kadobayashi et al., 2004; Nuttens et al., 2011).

Moreover, there is another gap regarding the lighting conditions in the alleys and zones beneath the historic wooden windows that may not always be convenient for image-based methods, and laser-based technologies alone may not be sufficient to extract the level of details required for the project.

Consequently, an approach needs to be devised to integrate both aerial and ground-based data acquisition. In line with that, Alitany (2014) presented the adopted augmented reality technology (AR-Media plugin) for visualizing the Roshan model, showing the potential of the application for educational purposes. However, users can only interact with the 3D model by visualizing it rather than recognizing the model in detail, and thus, they cannot obtain more information.

As suggested for mitigation, it is necessary to integrate both methods in some cases for ground-based data acquisition as needed. Figure 3.5 illustrates the aforesaid integration, as specified by Alitany et al. (2014).

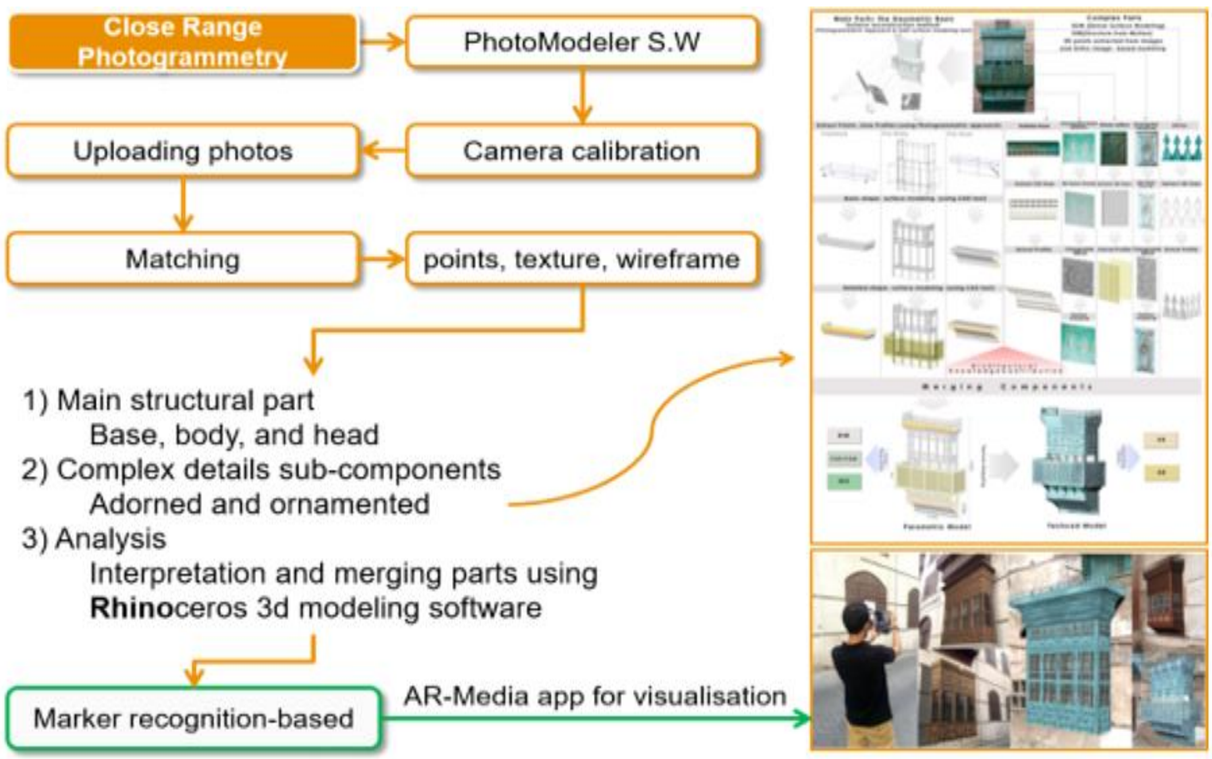

Figure 3.5: 3D CAD Modeling extraction integrated with AR app (Alitany et al., 2014)

3.3.2 HBIM/HGIS

3.3.2.1 BIM and HBIM

Most of the studies conducted focused on adopting Building Information Modeling (BIM) in the process of conserving historic sites (Pocobelli et al., 2018; Deniz, 2018; Fadli & AlSaeed, 2019; Ozcan-Deniz, 2019; Ma, 2021). These studies adopted either the BIM tool separately or integrated it with another tool for better accuracy. In the literature, many experts define BIM differently. Fosu et al. (2015) defined BIM as an advanced technology that could enable stakeholders to acquire and exchange information during the lifecycle of the building construction process, boost interoperability amongst industrial parties, and promote the popularity of these advances among them. Given that, one of the most distinguished features of BIM is its capacity to strengthen information transfer and facility management with constant client interaction through the life cycle procedures of the project (Dore & Murphy, 2012; Brumana et al., 2013; Chiabrando et al., 2016; Albourae et al., 2017; Liu et al., 2017). Some researchers have criticized these techniques. Willey (2009) argued that traditional 2D and 3D CAD was not sufficient because building practice depended on drawings and building design communication occurred through several documents, adding that CAD documents did not include all the information needed for an effective result in design evaluation and construction while pointing out that BIM was beyond drawings (Willey, 2009). However, BIM is considered the holistic process of creating and managing information for a specified built asset; therefore, the information related to the model is more important than the 3D model by itself.

Denis (2015) debated that BIM was defined as a software platform that allowed the coordination and combination of various stakeholders inside one BIM because it could be considered a three-dimensional object that was an oriented model that held information within it. This means that all elements composing the building are objects and are interdependent, whereas each element of the building has a specific relationship with others, such as windows and walls. Information can be found inside each object and can easily be defined and identified as a real element on-site (Denis 2015), whereas similarity describes the value added to BIM. On the other hand, BIM provides significant support to the project decisions in the making process, defining clear objectives, and understanding the interfaces by providing support to visualize design solutions, giving assistance to design, and increasing the quality of the building process. Given that BIM is an efficient exchange of data and geometry that allows more efficient construction, whereas construction can be achieved with higher accuracy and speed, it is therefore widely used and adopted in various applications and fields, such as the enhancement and documentation of historic structures.

Dore & Murphy (2012) have developed a significant approach for recording heritage sites digitally, which is known as Historic Building Information Modeling (HBIM). HBIM is, accordingly, a system to model historic structures from the data of laser scans and photogrammetry using BIM software. The HBIM process includes a reverse engineering solution, whereas parametric objects, which represent architectural elements, can be mapped into laser scans or even photogrammetric survey data. Generally, as soon as the geomatics survey is carried out through close-range photogrammetry or terrestrial laser scanning, the point cloud or its mesh, which is generated by the point cloud, can be modeled into the objects of BIM. HBIM is a useful tool that offers the critical potential to broaden the usage of cultural heritage knowledge and information (Chiabrando et al., 2017; Lanen et al., 2022). HBIM, consequently, is regarded as an emerging technology that enables us to document, understand, and advertise the heritage while exploring the usefulness and effectiveness of various methodologies developed for many models of the interest's elements and factors. Lombardi & Rizzi (2024) conducted a study on semantic modeling and HBIM, aiming to describe a methodological approach to represent, interpret, model, and manage pluristratified archaeological contexts. Their chosen methodology envisages a digital workflow, a BIM-thinking strategy that could integrate geometric and texture data obtained from laser and photogrammetric scans with information about construction techniques and materials, archaeological reports, and documentation. Such integration focused on a balanced combination of open-source and proprietary solutions while allowing professionals to work with their "comfort software" and, additionally, ensuring interoperability through the adoption of open standards. The authors conducted the experiments and explored the potential of connecting semantic 3D modeling and virtual reconstructions based on archaeological data made with Blender and the Extended Matrix Tool with BIM software and capabilities thanks to the BlenderBIM addon. Their offered workflow, in combination with the described data-sharing-oriented process, could adopt a new approach towards 3D models for promoting a more sustainable mindset towards the 3D dataset life-cycle by optimizing their usage and reducing waste on different levels, such as re-documenting the same structure twice. The findings illustrated the ability to generate semantic models that can enhance the comprehension of the context as well as foster multidisciplinary BIM collaboration, thus improving archaeological research, documentation, and conservation practices (Lombardi & Rizzi, 2024).

Chelaru et al. (2024) conducted a study while presenting a three-step process to improve heritage building data management using point cloud modeling, HBIM integration, and data extraction. The focus is on making data from historical sources and condition surveys more accessible. This will help decision-making for restoration, considering past context, current condition, and future work. The authors address metadata gaps, high modeling costs, and a lack of standards while asserting that future development will automate scan-to-BIM processes, increasing HBIM's value for architectural conservation (Chelaru et al., 2024).

Notwithstanding, the fields available in the BIM environment for the description and storage of the element are seen as limited. A 3D GIS environment, alternatively, can allow for building many fields as well as connecting many needed databases (Albourae & Armenakis, 2017; Osello et al., 2018; Vacca et al., 2018; Fadli & AlSaeed, 2019; Lombardi & Rizzi, 2024).

Many experts classified BIM models while employing two approximate scales: the level of detail (LoD) and the level of information (LoI). As to the LoD, it stands for the graphical elements of the model, whereas LoI stands for the non-graphical information. As to BIM data models, there are many. There is, for example, the gbXML (Green Building XML), which includes information for green building design, such as the geometry of the material, the building, and sensor information from more than one source. However, BIM data models can act as a significant single source of building information for the entire process. Another BIM data model is the Industry Foundation Classes (IFC), which can be used for implementing the suggested framework, yet gbXML is preferred by many experts because it provides more extensive coverage of the building compared to IFC (Osello et al., 2018; Vacca et al., 2018; Fadli & AlSaeed, 2019).

In summary, while BIM can significantly serve to geometrically and semantically model individual buildings and monuments in a local coordinate system, it is still becoming ubiquitous in the construction sector for its focus on CAD products. Given that, a Geographic Information System (GIS) can significantly contribute to the process of BIM by providing spatial input and geospatial visualization and adding information on the historic site's surrounding environment, which is considered essential for the process of design decisions as well as the approval processes.

3.3.2.2 Geographic Information Systems (GIS)

The term Geographic Information Systems (GIS) is generally understood as a special type of information system that can work with information on positional (geographical) characteristics. However, many authors define GIS in different ways. Huisman (2009) specified that GIS understands phenomena with spatial and temporal dimensions, meaning that the object of study has different features in different spaces and times. Accordingly, GIS technology can provide a detailed analysis of the earth's surface because many aspects of the environment are changing daily. ESRI (2011) defined GIS as an organized set of computer software, hardware, and geographic data that have been designed to effectively acquire, store, manage, modify, display, and analyze all forms of geographic information. Cano et al. (2013) stated that GIS has already proven to be helpful and effective in the archaeology field while allowing archaeologists and technicians to analyze all the available data and seek patterns amongst various layers of spatial data.

Hence, the process of using GIS to survey historic sites can read natural and cultural values and analyze urban and landscape conservation issues to reach a convenient approach to conserving, rehabilitating, and managing such historical heritage. Harder (2015) claimed that maps were significant tools that could tell stories while providing the user with an intensive experience, which allowed working and sharing. Therefore, maps are tools of communication information through which graphics can be understood faster. GIS technology extends the concept of the map by allowing the user to perform analysis on that data. Huisman (2009) explained that a person using

GIS could access geo-referenced data, whereas these data could be analyzed in several ways while producing presentations with it. In the context of cultural heritage, when the data is collected, it can be turned into a map. Central, local, and international authorities that are responsible for cultural heritage can then take advantage of the GIS technology as the main instrument to create corporate information systems, wherein the GIS information is one of the key data components in the system (Petrescu, 2007).

Notwithstanding, at present, no commonly accepted definition of GIS could suit all the fields to which GIS may be applied. However, each of the used definitions may include the main components, such as software, data, hardware, and organizational structure, whereas the main functions could be represented by analysis, input, management, data presentation, and system content (Vankova et al., 2022). GIS has been widely and diversely enhanced to link the various data genres with each other, analyze such spatial amounts of data preserved in databases, and manage heritage, considering the data genres including geospatial and geolocalized data, historic data, architectural data, and material data. Besides, recent advanced technology enables the sharing of such data via websites, such as WebGIS, which is considered an improvement of the conventional way of browsing and exploring geospatial data (GIS) (Vacca et al., 2018; Sammartano et al., 2023). Accordingly, various diverse approaches and efforts were conducted to improve the new GIS technologies and functionalities and to accommodate the application with the needs of architectural heritage, especially for restoration and maintaining purposes for such heritage. Deidda et al. (2015) used GIS for analyzing and managing the coastal defense system of Sardinia, which dates back to the 16^{th} and 18th centuries and is composed of 100 towers located and distributed on the extension line of Sardinia, whereas only one of those hundred towers was destroyed or missed. The authors of this application preserved both cultural heritage and landscape heritage and analyzed the historic assets. Vileikis et al. (2017) used GIS technology to explore and provide a strong comprehension of the Historic Centre of Bukhara, Itchan Kala, and Samarkand Crossroad as cultural and heritage cities in Uzbekistan, as well as the saving and managing tools of the solid heritage documentation. In brief, GIS is understood as a type of information system that works with significant information on geographical characteristics. The study by Moreno et al. (2022) admits that preserving heritage is challenging, especially during emergencies or budget constraints. Efficient and rapid hazard and vulnerability management becomes crucial for preventive conservation and prioritizing cultural assets. The authors introduce Art-Risk 3.0, the first freely available AI platform (to the authors' knowledge) designed to support conservation strategies for cultural heritage. It combines geographic information system (GIS) data with expert assessments using fuzzy logic to identify contextual threats and building vulnerabilities. Art-Risk 3.0 was applied to analyze 12 Spanish churches (11th–16th centuries). It analyzes hazard, vulnerability, and functionality indexes to classify buildings according to risk and optimize preventive conservation budgets. The system identifies dangers from geotechnical factors, precipitation, extreme weather, temperature fluctuations, earthquakes, and flooding. Using fuzzy logic, it interrelates these environmental factors with 14 structural risk and building vulnerability variables assessed through a literature review and image analysis. The study identified torrential rains and temperature fluctuations as the main environmental threats to Spanish heritage buildings. Furthermore, the Church of Santiago de Jesus was identified as the most vulnerable due to a lack of preventive conservation programs. This finding aligns with its inclusion on the Hispania Nostra list of endangered heritage, supporting the model's effectiveness.

Despite many definitions in the literature being provided to state the term GIS, recently there has been no commonly accepted definition of it to suit all the fields to which GIS may be applied. However, each of these definitions involved basic components, such as data, hardware, software, and the organizational structure, to represent its function through input, analysis, management, system contents, and data presentation. Settling upon the importance of both BIM and GIS in conserving historic sites, many attempts by previous researchers have been made to integrate them for better results in conserving heritage sites.

3.3.2.3 Integration of BIM and GIS and their Differences

Both BIM and GIS originated from overlapped domains, whereas they were developed to cope with the special requirements of professionals based in many fields. BIM systems focus on generating some objects with details considering geometry, whereas GIS systems are used to analyze many objects that are available in the real world (Fosu et al., 2015). There is a necessity to integrate both BIM and GIS to generate a georeferenced architectural database on the specified historic site, simply by creating Historic Geospatial Information System (HGIS) data.

The process of integrating BIM and GIS can establish indoor networks for specified emergency responses, expand the assessment of noise from regional levels to the indoor level, evaluate the influence of floods on the buildings, construct the buildings with the buildings with the highest energy effectiveness, trace the status of the supply chain, and minimize construction waste. Such integration can significantly offer mutual benefits, such as win-win outcomes, and form significant and strong synergy, in particular in the field of architectural heritage. However, such integration has many challenges, considering the main differences between BIM and GIS. Differences between BIM and GIS can be specified with a focus on data, processes, and application levels.

GIS (Geographic Information Systems) and BIM (Building Information Modelling) are two separate systems with different goals. While GIS is used to evaluate different items that are present in the actual world, BIM is primarily concerned with creating detailed models of the information of architectural 3D modeling out of the 2D drawing. It is a digital representation of a facility's physical and functional characteristics, serving as a shared information repository for collaboration throughout its life cycle while taking geometry into consideration.

While both BIM and GIS deal with geometry and attribute data, they serve distinct objectives and are frequently combined to give complete solutions for complicated projects, especially in urban planning, infrastructure construction, and facility management.

The creation of the Historic Geospatial Information System (HGIS) data, a georeferenced architectural database on a particular historic location, requires the combination of BIM and GIS. Geospatial visualization and geographical input are made possible by this integration, which offers details about the historic site's surroundings.

In order to include the historic site's physical coordinates and spatial context in the BIM model, georeferencing is necessary. HBIM uses a local coordinate system relevant to the building or location being modelled, despite HGIS uses a global coordinate system, such as latitude and longitude. By doing this, the BIM model aligns with the GIS data, allowing for a more thorough understanding of the site and making it easier to make design choices and go through approval procedures that take the site's geographic features into account. In order to integrate BIM models with GIS data and make sure they are appropriately positioned inside the site's geographic context, georeferencing is crucial.

3.3.2.3.1 BIM/GIS Data Level Differences

To begin with, GIS is typically used in a 2D or 2.5D environment. While some GIS applications provide 3D visualization and analysis, their primary goal is to represent and analyze geographic data in two dimensions or with minimal elevation information. In contrast, BIM is a 3D modeling system specifically designed to capture and manage 3D geometry and property data related to buildings and infrastructure projects.

The differences between BIM and GIS focusing on data level can be divided into geometry level and semantic level. As to the geometry level, the integrated methods focus on the differences in the reference system, the 3D geometric representation, and the level of detail (LOD) between both BIM and GIS. In the case of adopting the different reference systems, one can state that BIM can adopt a specified local placement system, whereas GIS can apply a significant geographic coordination system (GCS) (Bai, 2016; Ma & Ren, 2017; Ohori et al., 2017; Vacca et al., 2018). When transforming both systems, we need to calculate the matrix of transition, the bridging matrix M, and the origin difference Δ. There is another difference: BIM and GIS can represent 3D geometry in different ways, while BIM may adopt IFC as the standardized open data model that has three significant representation paradigms for volumetric objects, involving Sweep Solid (SS), Constructive Solid Geometry (CSG), and Boundary Representation (B-rep). While comparing with BIM, it appears that GIS adopts CityGML version 3.0 and shapefile as the most common formats of data. As to the CityGML format, it is clear that the boundary representation was just chosen to express 3D geometry. Therefore, we can form the solutions using many possible combinations between IFC (CSG, SS, B-rep) and CityGML/shapefile (B-rep) (De Laat & Van Berlo, 2011; Dore & Murphy, 2012; Vileikis et al., 2017; Ellul et al., 2017). For example, we can adopt the open-source computational geometry library VTK to implement the needed conversion from CSG to B-rep. Moreover, some authors, such as Deng et al. (2016), used the data mapping coordination system conversion function to obtain the intended conversion from IFC B-rep to CityGML B-rep while forming IFC Sweep Solid version 4.3 to CityGML B-rep. On the other hand, there is a difference between BIM and GIS focused on the level of detail (LOD), whereas IFC and CityGML have specified different classifications. However, according to the concept of LOD, both CityGML and IFC can divide LOD into 5 types, with IFC from LOD100 up to LOD500, respectively, whereas CityGML can be divided from LOD0 up to LOD4, respectively. Given that there are different definitions of LOD, there will be difficulty in the process of data mapping between both BIM and GIS. Concerning the semantic level, there are some significant challenges, such as the mismatch challenge linked to various definitions as well as the classifications of BIM and GIS. As an example, BIM can define windows, doors, and door openings as the indoor, ifcwindow, and ifcOpeningElement, whereas GIS may generalize them as windows and door openings. Generally speaking, whereas BIM offers detailed 3D visualization and can organize huge volumes of data on buildings, GIS is highly customizable and well-equipped for the process of analysis. Hence, GIS is ideal for projects in a specified multi-site environment. However, in constructing a building, there should be a specification of details in the design documentation; therefore, using BIM is preferred for obtaining more detailed results (Ma & Ren, 2017; Ohori et al., 2017; Vacca et al., 2018). Using GIS enables users to obtain more accurate geospatial models of proposals, plans, and the real world. GIS requires improvement to support orders of magnitude higher-density spatial resolutions.

The integration of BIM and GIS involves addressing differences, issues, challenges, and interoperability between the two systems. The differences between BIM and GIS can be categorized into data, process, and application levels.

At the data level, differences in geometry and semantics are identified. Geometry level differences include variations in reference systems, 3D geometric representation, and level of detail (LOD) between BIM and GIS. For example, BIM may adopt a local placement system, while GIS applies a geographic coordination system. Semantic-level differences refer to variations in how data is represented and interpreted in BIM and GIS.

The integration of BIM and GIS faces several challenges. One challenge is the conversion of data from one format to another, such as from IFC (Industry Foundation Classes) to shapefile formats. This conversion process requires addressing issues related to data integration and the use of case requirements. Additionally, there is a need to represent BIM and GIS data in a way that is easily understood, shared, and processed by both tools.

To address these challenges, different approaches for integrating BIM and GIS have been proposed. Some approaches focus on developing a unified model that includes both BIM and GIS data, while others concentrate on specific fields and phases of application. Integration methods include the use of new standards and models, the conversion and translation of existing standards, semantic web technologies, service-based methods, and application-focused methods.

Two approaches have been proposed for integrating BIM and GIS. The first approach involves the conversion of historic building information modeling (HBIM) to a geographic information system (GIS). This approach allows for the creation of a georeferenced architectural database on a historic site, forming a Historic Geospatial Information System (HGIS). The second approach focuses on the integration of BIM and GIS for an interactive user experience, particularly about geometrical and non-geometrical aspects.

This chapter discusses the integration of Building Information Modeling (BIM) and Geographic Information System (GIS) and addresses the differences, issues, challenges, and interoperability between the two approaches. Also, propose two approaches for integration and identify transformation problems associated with each approach.

Regarding the transformation problems, the dissertation mentions differences in the reference system, 3D geometric representation, and level of detail (LOD) between BIM and GIS. By highlighting the need to calculate transition matrices and origin differences when transforming between the two systems. They also note that BIM uses IFC as a standardized open data model with different representation paradigms, while GIS commonly adopts CityGML and shapefile formats.

To solve these transformation problems, the dissertation proposes techniques such as graph transformation and the use of ETL (Extract, Transform, Load) tools. Also, it mentions that graph transformation can be used for the accurate conversion of BIM models into CityGML city models. On the other hand, the dissertation states that ETL tools are convenient for bulk data conversion and can be customized for mapping between GIS and BIM platforms.

While providing solutions for the transformation problems, acknowledge that errors and limitations can still occur during the mapping and interpretation stages. Mentioning that human processing and the differences between HBIM (Historic Building Information Modeling) and GIS may lead to some manual edits and errors. Examples of errors in importing geometries and textures from BIM into GIS applications are also provided.

The two approaches have been tried to explore different methods of integration and to provide a comprehensive understanding of the integration of BIM and GIS and identify the strengths and limitations of each approach.

3.3.2.3.2 BIM/GIS Process Level Differences

At the semantic web technologies, at the process level, integrating both BIM and GIS will not change the format and structure of data; hence, we use the reference ontology as a significant part of the semantic web or web service to expand its cross-domain architecture mapping for storing and presenting the significant differences of objects. Semantic web technologies help in addressing data interoperability and meeting the data requirements for the design to a specified extent, despite some problems in leveraging semantic web technologies, such as Resource Description Framework (RDF) and Web Ontology Language (OWL). For example, there is no specified standard ontology and a requirement for the knowledge base, as specified by Karshenas (2015). Concerning service-based methods, they address BIM and GIS integration via the Internet instead of developing a new web service, which is considered effective due to semantic and geometric conversion as well as lesser information loss (Liu et al., 2017). For example, using a web-based system to analyze and visualize floods and disasters. In addition, it can assist users in linking various building levels and data domains, respectively, with a framework for 3D building.

3.3.2.3.3 BIM/GIS Application Level Differences

While exploring the differences between BIM and GIS, one can urge that at the level of application, generally, the integration ways include rebuilding, while suggesting modifying the existing BIM or GIS as a medium for exchanging and integrating the needed information, whereas such an integration way is inflexible and costly. For example, the customized plug-in obtained from BIM can be used for extracting information from GIS and storing it in the specified central database (De Laat & Van Berlo, 2011; Dore & Murphy, 2012; Vileikis et al., 2017; Ellul et al., 2017). Moreover, there is a misconception concerning the field of facility management that one should respond by searching for a tool that enables work at several layers, such as the building or premises. The facility management field is a discipline that has been dealing with the process of managing buildings and their related activities since its origin. Such a process needs knowledge of the buildings and their spatial arrangement (Vankova et al., 2022). BIM involves significant facility management information; e.g., in the model of architecture, the observer rarely sees spaces, rooms, or even a footprint of the specified building. GIS models have many uses for facility managers since GIS enables interpretation, surveying, insight into, and visualization of data, specifically from multiple points of view (Vankova et al., 2022). Thus, an integration of BIM and GIS capabilities provides a more detailed and clear picture of a multi-faceted project. Figure 3.6 shows the levels of differences between BIM and GIS.

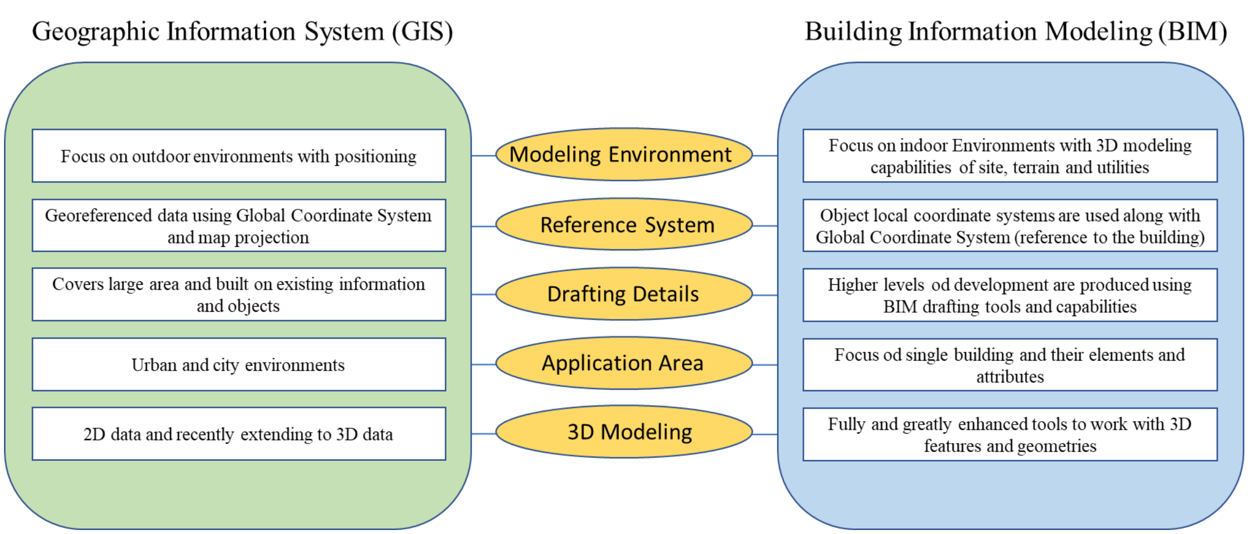

Figure 3.6: Levels of Differences Between BIM and GIS (Hor, A., 2022)

There are various benefits of integrating BIM (Building Information Modelling) with GIS (Geographic Information Systems) as opposed to the opposite. BIM is useful for modelling architectural elements in a local coordinate system since it offers comprehensive geometric and semantic information about specific buildings or monuments. In the building industry, where BIM is extensively utilized for CAD (Computer-Aided Design) purposes, this degree of detail is essential.

However, GIS is primarily concerned with the analysis and visualization of spatial data in the real world. Spatial input and geospatial visualization can be provided to BIM data by connecting BIM with GIS, giving important details about the surroundings of historic places. Gaining approvals and making well-informed design decisions depend on this spatial context.

3.3.2.3.4 Unveiling the advantages of bringing BIM to GIS

Several advantages of integrating BIM with GIS will be discussed in this paper. First of all, the Geographic Information System (GIS) offers the spatial context required to comprehend how buildings relate to their environment. Designers and planners can take terrain, land use, and infrastructure into account when making decisions by integrating BIM and GIS. Second, geospatial databases, aerial photos, satellite imaging, and other data sources can all be integrated with GIS. Better study and management of historic sites are made possible by the creation of a complete georeferenced architectural database made possible by the integration of BIM data with GIS.

While GIS provides strong analytical tools like geographical modelling, proximity analysis, and spatial querying, it also enhances analysis. More complex analyses, including determining the effect of floods on structures or determining noise levels at various geographical scales, can be carried out by integrating BIM and GIS. BIM offers a thorough and detailed representation of building information, including geometry, properties, and relationships. This is another advantage. The precision and specificity of geographical analysis in GIS are improved by this degree of detail.

Design and Construction Focus is another element that can be attained when BIM is mostly concentrated on the design and construction stages of a building project. Better decision-making throughout the planning and construction phases is made possible by the integration of BIM with GIS, which allows the spatial analysis to benefit from the precise design information.

Lastly, semantic and geometric conversion is possible with BIM to GIS GIS integration, guaranteeing proper information translation between the two systems. Effective data exchange is facilitated and information loss is reduced because to this conversion.

3.3.2.3.5 Limitations in bringing BIM to GIS

But merging BIM and GIS is not without its limitations and incompatibilities. Among them is the usage of disparate data models and standards by BIM and GIS. While GIS data models are intended for the analysis and management of spatial data, BIM data models concentrate on the specific physical and semantic details about individual buildings. It can be difficult to harmonize these data models, and conversion or translation of data may be necessary. Second, compared to GIS data, BIM models are usually more accurate and thorough. A choice must be made on the degree of detail to be preserved when integrating BIM into GIS. When moving from 3D BIM models to 2D or 2.5D GIS representations, this might be very difficult.

Another problem is that distinct attribute schemas and classifications may be used by GIS and BIM. It can be difficult to map attributes between the two systems, particularly when non-standard or bespoke attributes are involved. Furthermore, BIM integration with GIS can be a difficult and expensive procedure. Specialized software, knowledge, and resources are needed to guarantee smooth integration and data interoperability.

3.3.2.3.6 Unveiling the advantages of bringing GIS to BIM

Last but not least, although GIS covers a wider range of topics, including the surrounding environment and spatial relationships, BIM concentrates on specific buildings or structures. This narrow focus of BIM might limit GIS's ability to perform general analysis and make decisions.

First of all, by combining geographical data such as topography, land use, and infrastructure GIS gives BIM a spatial context. Improved comprehension of the building's surrounds and improved design and planning decisions are made possible by this spatial context. Second, GIS works effectively for projects involving several buildings or other structures in a multi-site setting. It supports thorough project management by making data from several locations accessible for analysis and visualization.

Lastly, a great degree of customization and analytical power are provided by GIS. Advanced geographic analysis is possible with it, including suitability analysis, proximity analysis, and spatial searches, all of which are useful for facility management and decision-making.

3.3.2.3.6 Limitations in bringing GIS to BIM

First of all, GIS usually falls short of BIM in terms of specificity and detail. It might miss important data like the materials used in construction, the intricate interactions between elements, or the parts of a building. After that, mapping and matching the various data models and classifications used in BIM and GIS can provide difficulties. Data integration and interoperability issues may arise from definitional and classificational discrepancies.

On the other hand, disparities in Representation: for 3D geometry, GIS and BIM employ distinct formats and representations. Although GIS often employs shapefile or CityGML formats, BIM frequently embraces IFC. The process of transforming and exchanging data between the two systems from 3D to 2D/2.5D and 3D to 3D can be complicated by these representational disparities.

Regarding 3D to 2D/2.5D and 3D to 3D transformations, these transformations involve converting BIM models, which are typically represented in 3D, into 2D or 2.5D representations suitable for GIS analysis. This conversion process may result in a loss of information or a simplification of the original 3D geometry. On the other hand, 3D to 3D transformations aim to maintain the full 3D representation of BIM models within the GIS environment, allowing for more accurate spatial analysis and visualization.

In summary, bringing BIM to GIS offers advantages in terms of geospatial context, data integration, and enhanced analysis. However, challenges arise due to differences in data models, level of detail, and attribute mapping. Transformations between 3D and 2D/2.5D or 3D to 3D involve trade-offs between information loss and accuracy, depending on the specific requirements of the integration.

Also, bringing BIM to GIS offers advantages in terms of detailed building information, design focus, and semantic and geometric conversion. However, it has limitations in terms of cost, limited scope, and potential data mapping challenges. On the other hand, bringing GIS to BIM provides advantages in a spatial context, multi-site environment, and customizability, but it may lack detailed building information and face challenges in representation and data interoperability.

3.3.2.3.7 Navigating the Differences and Challenges on the Integration HBIM and HGIS for the Conservation of Historic Sites

The integration of Historic Building Information Modeling (HBIM) and Historic Geographic Information System (HGIS) in Jeddah, Saudi Arabia, presents unique challenges and differences.

To begin with, on Spatial Scale, (HBIM) Focuses on specific historical buildings or sites with detailed representation at a smaller spatial scale. While (HGIS) Covers larger spatial scales, such as cities or regions, for broader historical analysis. The challenge encountered during the process of integration is Adapting to different spatial scales poses difficulties in maintaining data consistency and reliability in the integrated system.

Next up, in Integration Workflow Complexity, (HBIM) Involves detailed historical building modeling workflows. While (HGIS) Involves workflows for spatial analysis, often covering larger scales. The challenge inherent in achieving integration is Designing a complex workflow requires careful planning to seamlessly integrate processes from both HBIM and HGIS domains.Top of Form

Following that, in Texture and Geometry Limitations, (HBIM) Focuses on detailed geometric representation, including architectural textures. However, (HGIS) May have limitations in representing detailed building geometries and textures. The challenge encountered during the process of integration is Overcoming limitations in texture and geometry representation during integration.

Furthermore, Aligning Modeling Languages, (HBIM) Specialized form of BIM focusing on historic building documentation and conservation. Meanwhile (HGIS) Integrates historical data with geographic information, emphasizing spatial representation. The challenge faced with integration is Harmonizing different modeling languages involves resolving conflicts in semantic definitions and attributes.

Alternatively, Geometric Representation, (HBIM) Deals with the geometric representation of historic buildings. While (HGIS) Represents historical information spatially, including the location of events, boundaries, or changes in land use. The integration faces a challenge when integrating detailed geometric representation from HBIM with spatial representation in HGIS.

Furthermore, in computational complexity, (HBIM) Focuses on accurate spatial relationships within the building. But (HGIS) Uses a global coordinate system for representing geographic locations. The challenge of integration is Managing computational complexity when working with large HBIM files in conjunction with HGIS platforms. Efficient data processing is crucial for optimal performance.

Moreover, in User Experience and Visualization, (HBIM) Geared towards detailed building documentation and conservation. Whereas HGIS Aims to provide spatial context to historical information for broader spatial analysis. Integrating these systems requires Creating an integrated environment that involves tools for a seamless user experience. Enhancing the model with semantically complete information poses a challenge.

In addition, as Technical and Data Compatibility, HBIM is Based on the Industry Foundation Classes (IFC) standard., while HGIS Often uses CityGML for geographic information. the challenge faced with integration is Overcoming technical differences for effective interoperability. Overcoming technical differences involves addressing variations between IFC-based HBIM and shapefile format (used in my case) or CityGML-based HGIS for effective interoperability.

Additionally, Resolving Conflicts in HBIM Involves conflicts related to detailed architectural and structural semantics., while HGIS Conflicts may arise in spatial semantics, such as overlapping geographic features or conflicting historical events. The challenge is harmonizing conflicting information and resolving conflicts related to detailed and spatial semantics. Dealing with conflicts arising from multiple heterogeneous data sources during integration is crucial.

Subsequently, Data Heterogeneity, HBIM Deals with detailed geometric and attribute data specific to individual buildings., while HGIS Manages diverse spatial and attribute data related to historical events, sites, and cultural features over larger geographic areas. The challenge here is Addressing heterogeneity by managing differences in data sources, formats, and levels of detail for both HBIM and HGIS. Ensuring accurate data collection techniques is crucial for generating reliable models for both HBIM and HGIS.

Also, in Semantic Information and Differences, HBIM Captures architectural and structural elements with a focus on historical significance, cultural value, and architectural details. While, HGIS Focuses on spatial representation of historical information, integrating data on historical events, people, and cultural aspects. The Challenge of integration is Integrating diverse semantic information into a unified model.

Moreover, in Data Management and Storage, HBIM Deals with detailed geometric and attribute data for individual buildings, while HGIS Manages diverse spatial and attribute data for historical events, sites, and cultural features over larger areas. the challenges that face that integration are Addressing storage requirements, optimizing data management, and ensuring efficient handling of diverse datasets.

Finally, in **Coordinate Systems,** HBIM Uses a local coordinate system specific to the building or site being modeled., whereas HGIS Uses a global coordinate system, such as latitude and longitude, to represent the geographic locations of historical events or sites. The challenge of integration is Ensuring accurate alignment between local and global coordinate systems for seamless integration.

Addressing these challenges requires careful planning, the development of interoperability standards, data management strategies, integration workflows, and the use of appropriate software tools to achieve a successful and seamless integration of HBIM and HGIS for meaningful analysis and visualization of historic and spatial data.

3.3.2.3.8 Semantic Integration between HBIM and HGIS

Important roles for semantic data are played by both HBIM and HGIS. Semantic information in HBIM refers to the relationships and meaningful characteristics of architectural elements, like their materials, function, and historical relevance. It makes it possible to produce intelligent 3D models for decision-making, analysis, and simulation. Semantic information is utilized in HGIS to characterize and arrange spatial data, making it easier to integrate different datasets and perform spatial queries and analysis.

It facilitates comprehension of the historical background and geographical relationships between various heritage features. A thorough understanding of the built heritage and the support of successful conservation activities are made possible by the smooth interchange of semantic information between HBIM and HGIS. Through the use of semantic information, scholars may create unified information retrieval systems, integrate large-scale datasets such as CityGML, and advance international heritage conservation initiatives.

Semantic in HBIM (Historic Building Information Modelling) refers to the characteristics and relevant information connected to the model's building elements. It contains information about the building's historical significance, architectural style, building materials, and any other pertinent details that contribute to a better understanding of its heritage value.

Semantic data, both spatial and non-spatial, pertaining to historical places and events is referred to in HGIS (Historical Geographic Information System). It contains details on the boundaries, geographic coordinates, historical maps, images, records, and other contextual information that aid in assessing and deciphering the historical value of a specific location or site.

3.3.2.4 Approaches for Integration of BIM and GIS

Many approaches have been offered by experts to facilitate BIM and GIS integration, focusing on special concepts, whereas each of these concepts was centered on the specified objective of this integration or generation, which was a reflection of their own beliefs (Letellier, 2007; Eppich et al., 2012). Fosu et al. (2015) demonstrated that, in the field of heritage conservation, many studies attempted to establish their approaches based on the integration type used, such as BIM/GIS, GIS/BIM, BIM and GIS, Unified Building Model, or Web viewing applications. Fosu et al. (2015) found that although many attempts have been made with accuracy in this field, the studies that applied solutions with examples were few and limited to some case studies and situations, while their approach was convenient only for specified conditions that cannot be applied to other situations.

BIM/GIS integration approaches have a resulting model that can be hosted on a GIS platform (Zhang et al., 2009). BIM and GIS integration offers a novel Data Inspector approach or concept to integrating BIM and GIS through new extensions, tools, ontologies, or frameworks (de Laat & van Berlo, 2011; Kang & Hong, 2015). The Unified Building Model deals with developing a separate unified model that includes both BIM and GIS data (El-Mekawy & Stman, 2010; El-Mekawy et al., 2011; El-Mekawy & Stman, 2012; El-Mekawy et al., 2012). Web viewing applications venture to a specified route of converting BIM and GIS data, especially for web visualization (Wu et al., 2014). In the current approach, the data was made to be shared via the website using the potential of technologies, such as WebGIS technology.

Liu et al. (2017) focused on BIM/GIS integration at various levels: data level, process level, and application level. Those levels depend upon the type of task that requires this integration, such as preserving historic buildings or planning at sites. Going ahead with this concept, Liu et al. (2017) focus on EEEF criteria. EEEF stands for effectiveness, extensibility, effort, and flexibility. To shed light on these chosen criteria of EEEF, the following Table 1 represents a comparison of the integration solutions by the criteria of EEEF.

Table 3.1: Comparison of BIM/GIS integration solutions by EEEF criteria (Liu, et al., 2017)

Integration Methods	Effectiveness	Extensibility	Effort	Flexibility
New standards and models	Case by case	Case by case	Case by case	Case by case
Conversion, translation, and extension of existing standards (manual)	Medium	High	High	Medium
Conversion, translation, and extension of existing standard (Semi-automatic)	Medium	Medium	Medium	Medium
Semantic web technologies	High	High	High	Medium
Services-based methods	High	Low	High	Low
Application focused methods	Case by case	Low	Low	Low

Liu et al. (2017) asserted that such integration of BIM and GIS was originally developed for various purposes, while many challenges were encountered during such integration. Therefore, the integration aims to solve such challenges. In the same context, Ma & Ren (2017) demonstrated that the integration pattern of both models varied between the literature studies and was classified as data extraction from GIS into BIM systems, data extraction from BIM into GIS, and data extraction from both GIS and BIM into a third system. The case of data extraction from BIM into a GIS pattern constituted a repeating trend of interest in the literature. Regarding the model that will be proposed in our study, it will accommodate the pattern of extracting GIS and BIM data into third-party systems.

Baik et al. (2015) insisted that an integration-based solution could be used to create the documentation and provide conservation of more than 600 historic buildings while creating the possibility of generating documents and analyzing many cultural heritage sites. Hence, the state of the arts based on such a solution should be understood. Baik et al. (2015) have presented a method that suggests converting historic building information modeling (HBIM) to a geographic information system (GIS) by having the JHBIM model hosted on a GIS platform, as illustrated in Figure 3.7. JHBIM stands for Jeddah Historical BIM.

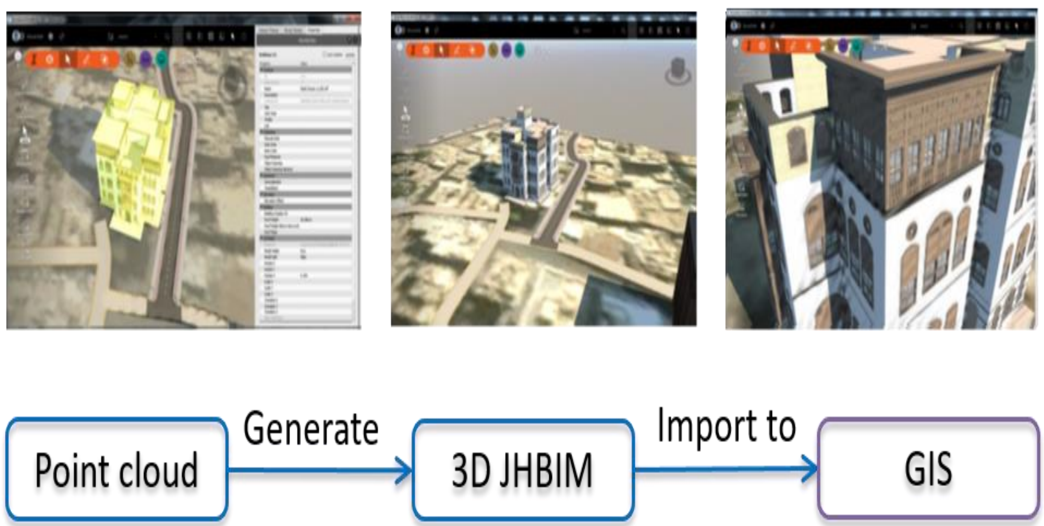

Figure 3.7: Integrating HBIM into GIS of Nasif Historic House (Baik et al., 2015)

Using this integrated approach (HBIM into GIS), Baik et al. (2015) have created a model of the Nasif Historic Building, which was semantically complete with non-architectural aspects, including the used material, the historic context, and the history of restorations that occurred on the building. Though such information may be useful for tourists and researchers, they have not supported their studies to generate a georeferenced architectural database by creating Historic Geospatial Information System (HGIS) data.

Lanen et al. (2022) conducted a study focusing on Schokland (NL), the former island in Dutch Zuiderzee while presenting a new Historic Geographical Information System (HGIS) designed specifically to integrate geoscientific and cultural data and facilitate dynamic heritage management. Their results showed that HGIS could add greatly to the contextualization and digital accessibility of this heritage site and could be seen as fundamental for substantiating the conservation methodologies. They commented further that HGIS could show great research potential for the diachronological reconstruction of dynamic lowland development. HGIS accordingly could facilitate multidisciplinary scientific analysis, integrated monitoring, and public outreach, and most importantly, showed great application potential for other heritage sites around the world (Lanen et al., 2022). Settling upon that, there are many examples illustrating the process of integrating BIM and GIS, such as CityGML and Industry Founds Classed (IFC) models.

The transferability of the technique was proved by the introduction of a novel way to integrate the Historic Geographic Information System (HGIS) with Historic Building Information Modelling (HBIM) for the historic site of Jeddah and similar locations. Through the development of a workflow process utilizing commercially available tools, the author guarantees the integrated model's transferability and ease of implementation. One of the dissertation's outcomes is the establishment of a historical database that the site's conservation stakeholders can use and access.

For the Jeddah historic site and other sites of a similar nature, the integration of HBIM and HGIS delivers various new contributions. First, using off-the-shelf (COTS) application software, the author created a way for merging HBIM and HGIS. This integrated model can act as the basis for an HBIM and HGIS data-driven cloud-based cultural heritage database that can be utilized for tourism and educational purposes.

The author also presents methods for modifying and improving data in the semantic-based model by employing workflows and spatial ETL (Extract, Transform, Load) tools from HBIM and

HGIS platforms. By concentrating on the Jeddah historic site and its unique challenges—such as the documentation and conservation of historic wooden windows and the integration of Jeddah Historical HBIM and 3D HGIS for the documentation and restoration of historical monuments—the work also fills in gaps in earlier research.

The work's potential applicability to other comparable historically significant locations demonstrates its transferability. The techniques and strategies created in this research can be modified and applied in various settings to combine HGIS and HBIM for cultural heritage management and conservation. However, when using the integration technique, it is imperative to take into account the unique qualities and difficulties of each site.

3.3.2.4.1 CityGML and Industry Foundation Classes (IFC) Models as an Example of Integrating BIM and GIS

BIM and GIS integrated systems are of common interest in modeling building objects; despite the diverse proposed models, differences are shown in the encoding of geometry, semantic utilization, and level of detail (Ohori et al., 2017). These differences can be mainly illustrated through the clarification of both standards of the CityGML model and the Industry Foundation Classes (IFC) model as examples of integrated models. Given that, the industry standard for exchanging BIM can be defined by the Industry Foundation Classes (IFC). Details of GityGML and IFC are explained below.

3.3.2.4.1.1 CityGML Model

The CityGML model is a standard for preserving and exchanging 3D city models in terms of the GIS domain semantics. The model applied the geography markup language as the main scheme of implementation. The model consists of 12 modules with different cases, each of which consists of different objects. The differences among classes are defined in the objects' structures and attributes, despite the geometric basis of all objects, where all share 3D surfaces and both triangular and polygonal faces (Tauscher et al., 2021).

CityGML defines five levels of detail: LOD0, LOD1, LOD2, LOD3, and LOD4 (Figure 3.8). LOD0 is a building's non-volumetric roof surface representation. LOD1 is the blocked shape of the building. LOD2 is a representation of the generalized roof with integrated installations such as balconies. LOD3 is a building representation with additional installation details such as doors, windows, and architectural exteriors. The LOD4 is the last interior design representation of the building, such as furniture (Kolbe, 2009; Goetz, 2013; Boeterset et al., 2015; Tauscher et al., 2021).

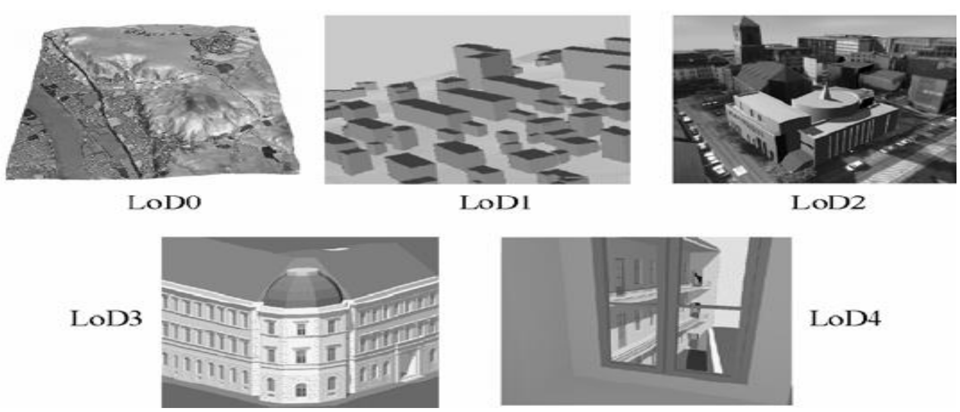

Figure 3.8: The five Levels-of-Detail (LOD) defined by CityGML (Kolbe, 2009)

3.3.2.4.1.2 IFC Model

IFC is the Industry Foundation Classes model-based BIM domain for exchange construction models, commonly including the 3D building model. Technically, IFC can be defined using the ISO 10202 suite of specifications for data modeling and exchange, recognized as the Standard for the Exchange of Product Data (STEP). IFC has been taken up by many CAD vendors, especially in the architecture field. The language of the IFC is so complicated, including over 327 data types, 653 entity definitions, and 317 property sets (Steel & Drogemuller, 2012; Tauscher et al., 2021). However, technically, IFC and its usage in the construction and design industries can represent such interesting research since the domain may be challenging due to its breadth and size. The paradigm representation includes primitive instancing, constructive solid geometry (CSG), sweep volumes, and B-rep. Primitive instancing is the object representation based on predefined parameters to define mainly the 2D forms in IFC and the volumetric presentation of objects such as cones. CSG performed the Boolean set operation on the volumetric objects, which was used for deleting the undesired parts of objects. Sweep volumes are solidly constructed through the 2D profile and a curve alongside extruded surfaces, and B-rep is a bounded surface object including either triangulated, polygonal, or topological meshes of free-form surfaces (El-Mekawy et al., 2012; Tauscher et al., 2021).

For accurate conversion of the IFC building model into CityGML city models as one of the most important operational scenarios for integrating BIM-GIS, a study conducted by Tauscher et al. (2021) adopted the technique of graph transformation as a significant conversion method, which fulfilled such requirements. The authors proposed extending the modularity given by single transformation rules, especially at a more coarse-grained level, while identifying four layers with the modules of the associated rules. They described the self-contained set of rules significantly across such modules and illustrated its application to the range of the building models. Their main objective was to mitigate the issues behind solving the practical data integration, such as the challenges of conversion from IFC to CityGML adjusted to the input model and the usage of case requirements (Tauscher et al., 2021). Their approach has a significant potential to be applied to other needed domains, such as converting IFC to other formats similar to Green BuildingXML or Indoor GML from other sources, including sensor data or even public transportation data (Tauscher et al., 2021).

In summary, the previous studies on the integration of BIM and GIS fall into two main types: one that concentrates on the application in specified fields for specified phases, and the other that proposes a unified model for the comprehensive management of the entire lifecycle. However, those experts who focused on the first type used different integration platforms and patterns, while those who researched the second type still lacked sufficient validation and practice in various fields for the entire lifecycle. There is a gap linked to how we can represent the data in BIM and GIS and their semantics in a creative way that can be easily understood, shared, and processed by both tools.

In line with that, we see that HGIS could be integrated with HBIM and complimented for an interactive user experience, which provides highly descriptive models corresponding to the complexity of geometrical and non-geometrical aspects. Additionally, integrating HGIS with HBIM can focus more on presenting the power of the architecture part of the historic building rather than providing accurate and updated data, such as road networks obtained from Open-StreetMap and elevation obtained from USGS National DEM, given the fact that the 3D historic model is not accessible to detailed exploration. Notwithstanding, the new data resulting from integrating HGIS with HBIM can be utilized, as in the case of this study. For example, using 3D viewers and a mechanism can be useful to create unified spatial queries to pull information from unified models.

In this study, our proposed approach aims at integrating these methods to get the maximum benefits for the sake of tourists and academic researchers while generating a significant, exhaustive reference database for future projects related to heritage conservation. We see that studies should specify which sectors of the Architecture, Engineering, Construction, and Owner/Operator (AECO) industry have to adopt the available technologies more readily to assess how different organizations are adapting and evolving as an outcome of those advances and applications of integrating BIM and GIS.

3.3.3 Interactive and Immersive Technologies

Interactive technologies are considered the world leaders while allowing for a two-way flow of the specified information, namely through an interface between the user and the technology. Interactive displays make it possible to make changes at the right time for any sudden circumstances. Immersive technologies can create specified, distinct experiences simply by merging the physical world with a simulated or digital reality. Augmented reality (AR) and virtual reality (VR) are two main types of immersive technologies that can easily share many similar qualities (Capecchi et al., 2024). Utilizing interactive and immersive technologies in the conservation of heritage sites offers significant value by digitally reconstructing and documenting historic heritage for posterity (Albourae et al., 2017; Andaru et al., 2019; Soto-Martin et al., 2020; Poux et al., 2020; Vileikis et al., 2023; Capecchi et al., 2024).

3.3.3.1 Augmented Reality (AR) and Mixed Reality (MR)

Many experts defined and used the term "Augmented Reality (AR)" in several studies. Following a study conducted by Bowman (2008), AR is defined as a system whereby the user can view and act with an enhanced version of the real and the virtual world. AR is seen as a significant technology, which can overlay computer-generated imagery and information on the real environment, to improve or augment the contextual perception of the users' surroundings. The process of augmentations can be visualized using a tablet, mobile device, or even a head-mounted display (HMD). However, there are some improvements made virtually and generated by computers while information and objects can be included in this process. Figure 3.9 shows the transition of Reality and Virtuality. What exists within it can be defined as Mixed Reality (MR) that if turned will be divided into AR and AV.

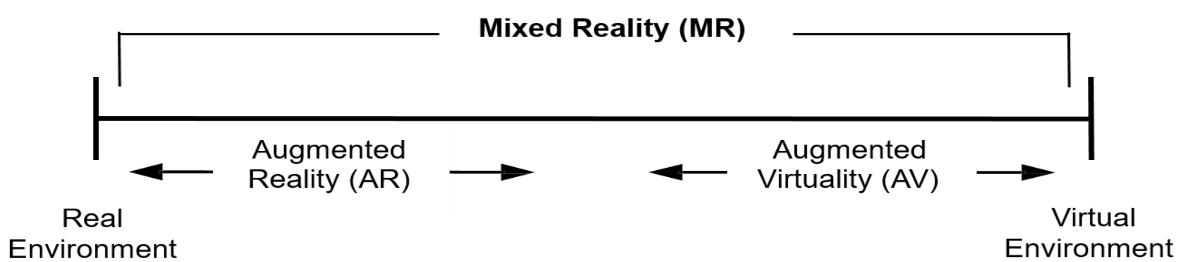

Figure 3.9: Milgram's Reality-Virtuality Continuum

AR/MR can be applied to diverse areas, including maintenance, training, tourism, cultural heritage, design and construction, and battlefield information display. It is a system that enables tracking, including source-less inertial orientation tracking and GPS position tracking. Therefore, this system can be integrated into the BIM model and the 3D GIS model to conserve cultural heritage. The challenge with AR interfaces is that there might be conflicts between the real and virtual worlds, whereas the display is also limited. The spatiality of the display of the display can be limited, and tracking could not be precise. Furthermore, registration cannot occur in a fast way, whereas some limitations can be found in controls. Many attempts have been made to overcome such challenges (Bowman, 2001).

3.3.3.2 Virtual and Augmented Reality in Cultural Heritage Applications

Virtual reality and augmented reality have developed rapidly while being used in many fields, though there is still opacity in the concept among individuals. However, the most familiar form of VR is the gaming application (Cirulis et al., 2015; Setyawati et al., 2019; Delgado et al., 2020).

Virtual reality (VR) is considered a technique that creates virtual environments generated by computers while replacing the perception of the users of the surrounding environment with a virtual environment using glasses, HMDs, and multi-display setups (Steuer, 1992; Delgado et al., 2020; Capecchi et al., 2024). Digital documentation has the potential to integrate with an enhanced virtual environment where users can experience virtual walkthrough sites without having to visit the site physically. It can also assist tourists in choosing potential sites to visit before planning their travel. Similarly, augmented reality (AR) is a combination of computer-created and real information interactively in real-time and in a real environment that aligns virtual objects with real-world or physical ones (Höllerer & Feiner, 2004; Delgado et al., 2020). Therefore, it can also be used to project computer-generated objects onto heritage sites, increase digital accessibility, and remodel a particular time in history, giving the users a more fulfilling experience. In terms of cultural heritage, VR is mainly used for visualizing historic and cultural resources and sites, such as old canals, railways, battlegrounds, and ancient sites (ancient groves, springs, stones, and trees), mainly in museums and historic settings, where these settings have adopted a recent way to transfer and exchange information with the general public, where interaction is the distinguishing feature of the settings, which is unprecedented in a passive experience. This process is fostered by tourism activities and technologies, where heritage is considered the main captivating tool for tourist destinations (Cirulis et al., 2015; Delgado et al., 2020).

Geguti Palace is one of the cultural and historical buildings that have been modeled in virtual experience applications by Ferrari & Medici (2017). The authors started with the digital documentation and prior 3D survey of this historic palace that has been achieved and developed by the Department of Architecture of the University of Ferrara and the Tbilisi State Academy of Arts in collaboration with the National Agency for Cultural Heritage Conservation of Georgia, as illustrated by Ferrari & Medici et al. (2017). They employed Geomax Zoom 300, a time-of-flight laser scanner, NCTech iStar 360, a spherical camera by NCTech, and a Samsung WB690 compact camera for photo-modeling. Their results provided valuable information on the benefits of adopting this technique. Initially, the content of VR was developed to be experienced via Wimius 3D VR HMDs, and immersive experiences based on 360° images and video were built using the Affinity software to edit the 2D-dimensional planer (Ferrari & Medici, 2017). Further, the authors utilized 360° roaster images to create videos that enriched the readable contents of the metadata. The authors emphasized that, in the first seconds of the experience, only the spherical environment was shown; after 15 seconds, the first textual information and graphical elements were shown, respectively, as guidance for users through the experience (Ferrari & Medici, 2017).

A study on VR application for cultural heritage—a VR-WEB-BIM for future maintenance of Milan’s Cathedral by Fassi et al. (2016)—addressed three basic areas: surveying the structure, constructing a detailed and accurate 3D model to produce the planned measurements, and developing BIM to gather all the available data on the projects, previously, recently, and the future activities of the cathedral's maintenance. Their findings highlighted two important points: a high-appeal visualization system to allow a virtual visit of the Main Spire of the investigated cathedral, the highest part of the building; and the second point was related the possibility of using such technology for the sake of exploring virtually this cathedral significantly, from a technical perspective, while using immersive visualization for better comprehension and awareness of the structure and obtaining up-to-date information on the state of conservation, involving the current and previous activities of maintenance, as in the augmented reality system in the virtual real environment (Fassi et al., 2016). Though the geographical differences in the heritage buildings' locations may vary, the sites are based on an upward analysis of the methodologies that can be exchanged between continents. However, our study is different from theirs, while generating and integrating HBIM/HGIS with immersive and interactive technologies to provide better results and facilitate users' interaction with VR, respectively.

Mixed reality has the concept of a cyber-real interplay space, and this interactive narrative promotes new patterns of understanding (Papagiannakis & Magnenat-Thalmann, 2005). There are a considerable number of projects exploring AR-integrated platforms in different domains, like cultural heritage (Setyawati et al., 2019; Soto-Martin et al., 2020). This technology is applied in design and architecture to provide many AR-enabling technologies and frameworks. Few of the available AR systems can provide realistic mixed reality applications, as they rely on many elements such as real-time camera tracking, AR display and interfaces, and registration technologies. The view of the superposition of the real world in a virtual environment represents simulated living characters in real-time. The sensation of presence is reinforced by the occlusion of virtual objects in virtual augmentation. It causes believable behaviors and interactions between real and virtual objects (Papagiannakis & Magnenat-Thalmann, 2005).

Art, the Orangery, and Public Realm were launched by The Hepworth and Wakefield College to explore the potential of a 3-year program for artists. The capacity for orangery was developed (Virtual Orangery, 2012). The Orangery was located in Wakefield. Scan to BIM to Virtual was the main approach workflow for visualizing the data in this project. The contracted company proposed creating an online model of Orangery using BIM, which should be accessible to the public. In this project, achieving user-friendly web-based interfaces that are accessible to the public became a challenge. The project used Point Cloud to scan the building and its surroundings to create a virtual model (Virtual Orangery, 2012). Different architectural construction plans were extracted from the BIM model. Two companies worked collaboratively to conduct research and deliver visualizations of the building. The experience provided by this project was an integration of point cloud capture, the conversion of this information into a BIM model, and a translation to a web 3D interactive model. This model was finally converted into a simple online interface with a sample game-style interface using Stadia 3D and Unity 3D. Finally, the last step of this process was to convert the BIM model using Unity 3D into a virtual interactive model for public access using a web navigator like a game, where one can have the autonomy to move and control while also interacting with the model. However, the limitation of this project was that the GIS capability was not provided and could not be shared easily with the public, and there were no query functionalities for each component that supported the interactive user experience.

Today, when individuals visit a cultural heritage site, they cannot grasp the ancient, vibrant life of that place. This is very visible in ruins, for example. With AR-enabling technologies, it is possible to provide obvious images to theaters (Papagiannakis & Magnenat-Thalmann, 2005). Buckland & Wilcock (1973) predicted that computers could be used to recreate archaeological sites. Indeed, the first step towards 3D digital documentation of archaeological objects was published by Biek (1985).

Later, extensive research was conducted on the conservation of sites, such as the Roman bath at Caerleon, South Wales (Arnold et al., 1989). Accordingly, the graphics' work started a short time ago, while the early results were mixed. The experiments, including 3D recording and illustration, were the most exciting developments at that date, whereas the analysis of the surface topography of the related cemetery promised some results. Taking further spot-height readings would be critical in these areas, where there was a suspicion of some new mounds. According to their results, the site's presentation to the public included much more advanced graphical techniques, whereas the modeling represented some challenges that might be resolved in the future (Arnold et al., 1989).

The previous conservation site for Michelangelo's sculptures took place in Florence, Italy (Levoy et al., 2000). According to the study of Levoy et al. (2000), they described a software and hardware system for digitalizing the color and shape of large, fragile objects significantly under non-laboratory conditions. Their system could use laser triangulation rangefinders, digital still cameras, laser time-of-flight rangefinders, and a suite of software that has been acquired, aligned, merged, and viewed scanned data. They could digitalize 10 statues, simply by Michelangelo, involving the figure of David, two building interiors, and all the 1163 extant fragments of Forma Urbis Romae. Their dataset consisted of David, 2 billion polygons, and 7000 color images. The researchers focused in their study on the unusual design of their laser triangulation scanner as well as on the software and algorithms they developed for handling the large scanned models (Levoy et al., 2000).

Referring to the ancient marble map of Rome, constructed in the early 3rd century (Koller & Levoy, 2006). Following the statement of Koller & Levoy (2006), they explained their efforts to apply computer-aided reconstruction algorithms, find new matches, and position themselves among Forma Urbis Romae’s fragments. Initially, they reviewed the fragments’ attributes, which appeared as useful clues for the automated reconstruction. Later, they explained several various methods, which they developed and made use of geometric computation capabilities and digital fragment representations to suggest new matches. Such methods were illustrated with some fragment joins and placements, which have been generated from their computer-aided reconstruction process.

Furthermore, various low-cost AR applications were adopted to serve the archaeological sites (Aguilo´, Lore´s & Junyent (2001), & Gleue & Dähne (2001), which proposed an AR prototype for archaeological site visits, which a six-degree freedom visualization experienced via a tablet PC as an outdoor application. However, in both Gleue & Dahne (2001) and Vlahakis et al. (2001), the archaeologists used AR technology for the reconstruction and restoration of ancient ruins. The system used the Differential Global Positioning System (DGPS) to obtain the user's positions, a compass, and real-time image rendering to align the reconstruction view based on.

Recently, Ozcan-Deniz (2019) conducted a study while attempting to answer the question, “How to achieve a successful connection between BIM and VR, to present a significant dynamic demonstration of the real-case complicated models?” In answering this question, the author specified the objective: to develop a conceptual map to present the aimed-for successful BIM/VR integral systems. The chosen methodology involved developing a 3D model, assessment, and enhancement of the design for VR aims, as well as integrating BIM and VR systems (Ozcan-Deniz, 2019). Such specified BIM/VR systems could offer a specific virtual mock-up of assessed and improved BIM by contractors, designers, and users of the buildings. The findings involved the developed steps of the BIM/VR system along with testing through the virtual walk-throughs, as illustrated in Figure 3.10.

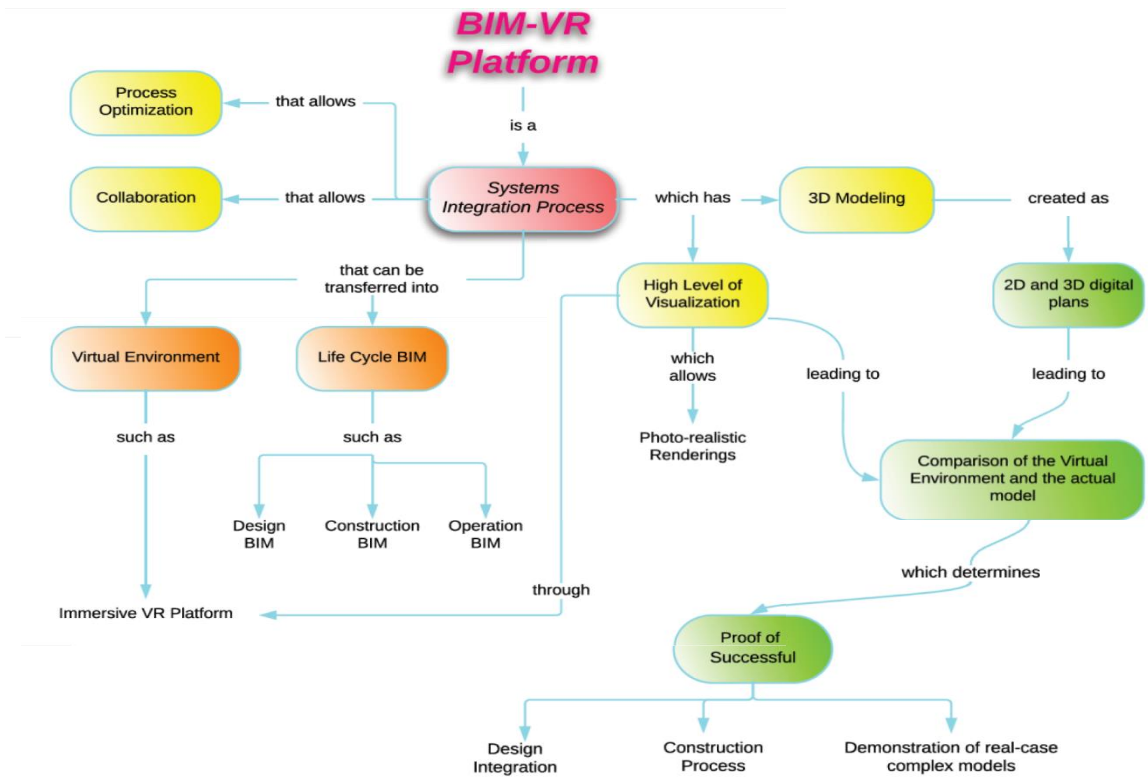

Figure 3.10: BIM/VR systems integrated concept map – (Ozcan-Deniz, 2019)

Based on the work of Ozcan-Deniz (2019), the findings that were developed through the best steps of the BIM/VR system and testing through the virtual walk-throughs are considered significantly valuable to continuous immersive VR users, in particular in academic research and the Architecture Engineering Construction (AEC) industry. While appreciating the efforts of Ozcan-Deniz (2019), our study focuses on generating and integrating HBIM/HGIS with immersive and interactive technologies to provide better results and facilitate users' interaction with VR.

There are many valuable platforms for mixed-reality systems, such as smartphones. Smartphones can facilitate the process of connection with construction while aiding in the recognition of the exact location using GPS, compass signals, and some of the attached cameras. Keil et al. (2011) have developed an iPhone-based app as an architectural and historic guide for tourism, in particular in investigating cultural heritage sites. These sites included Darmstadt’s Mathildenhoehe, the famous Artist’s Colony, with the leading architect’s residence, the Josef Maria Olbrich House, as the main example (Figure 3.11). This app provides textual information regarding the buildings’ architecture and offers a 3D model vision when run in a ‘classic information tour’ style. However, when running in an ‘augmented reality tour’ style, the user can take a snapshot of the building ahead, and after recognizing the building, a 3D reconstruction of the full building can appear with significant information on its changed or missed elements.

The 3D reconstruction reacts to the user’s position and movements using data from the phone’s compass and GPS. It also reacts to two-finger multi-touch pinch, rotating, and zoom gestures. While this app can provide the user with important information, the 3D model used in it has a sketch-like rendering, which limits the 'reality' aspect of AVR. Thus, the architectural elements of the model cannot be examined in detail.

After generating the chosen 3D model, it will be fed into AVR platforms (desktop PCs, wall-mounted displays, or head-mounted displays) to provide the user with an immersive experience. This is while paying attention to the fact that specific models with different levels of detail are required for different purposes. For example, in the conservation model, a high level of detail is required, whereas lower levels of detail are significantly needed to provide more information to the tourists. A high level of detail means a large volume of data that makes it difficult to insert into the portable device used by tourists. However, for the proposed application, there will be two components, whereas the VR component will enable the users to virtually walk fast and inspect the models by using some interactive devices. As to the AR component, there are still some enhancements to be added to the previously generated 3D model.

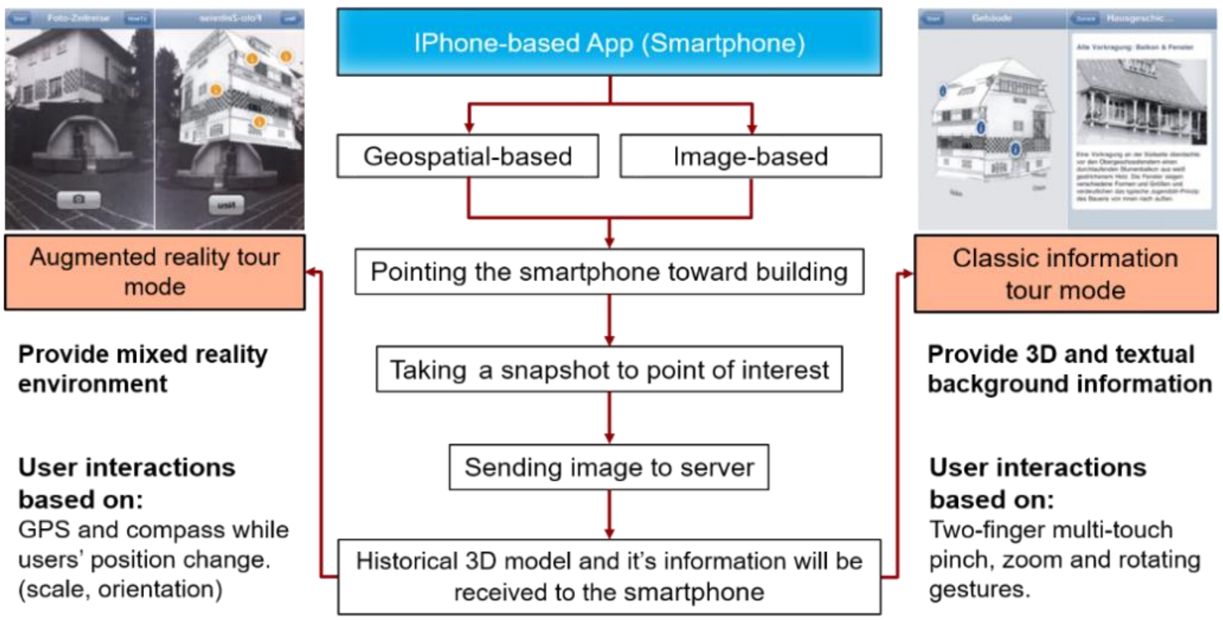

Figure 3.11: Summary of a Related Work for AR Component (Keil et al., 2011)

Despite the critical benefits of using VR and AR, such as the spotlights shining brightly on them, geomatics experts nowadays have subdued their working expectations in an augmented or virtual world (Wegen & Kodde, 2017). Wegen & Kodde (2017) conducted a study on the advancing industry of geoinformation while seeking the latest trends and evolutions in the surveying industry. They insist that 3D modeling is a critical theme while both AR and VR are being illustrated to create considerable value.

Another study conducted by Poux et al. (2020) explained new methods to interact with high-quality 3D reconstructions significantly in a real-world scenario. The authors proposed a user-centric product design to create a specified VR application aimed at multi-modal applications. Their suggested study was applied to the Castle of Jehay, Belgium, which was under renovation, to allow a multi-user digital immersive experience (Poux et al., 2020). Their study proposed a high-level view of the multi-disciplinary processes, significantly from a requirements analysis to the 3D reality capture workflow as well as the process of creating a VR environment into an immersive application. However, the authors provided several relevant VR parameters for such scene optimization, the locomotion system, and additionally, the multi-user environment definition, which were tested in the specified heritage tourism context (Poux et al., 2020). However, what is critical is not having such techniques implemented but rather managing the integration of those evolutions into a modular system. Needless to say, extra work is still needed to investigate the best methods of incorporating reality capture data modalities, such as point clouds, significantly without any of the geometric and scene optimizations.

3.4 Requirements

While appreciating the efforts of the previous authors, we extend their ideas while suggesting that the architecture of this present research include the following components for the integration of HBIM and HGIS:

1. Developing a workflow to integrate LiDAR-based data, image-based data, and surveying technologies to generate a 3D model of the target site.
2. Modeling: georeferenced 3D models of heritage architectural elements.
3. Investigating architectural elements: to provide future users with relevant data to understand heritage sites and their evolution.

4. Implementing 3D models: using BIM tools integrated with a GIS to provide semantically complete information models as a separate, unified model.
5. User contribution and experience: the output of the integrated models for the development of the AVR application, which provides the users with an immersive experience complemented with interactive contextual information.

Summaries of the requirements include generating the 3D model of the site, georeferencing 3D models, checking the architectural elements, and implementing 3D models (BIM integration with GIS). Finally, the output of the AVR provides the user with an immersive and interactive experience of the information. The issues faced are explained in the last chapter of this study under section (limitations).

However, such requirements will fulfill the methodological process of conducting the suggested project, its modeling, and its design. Based on the previous literature survey, the next chapter will specify the existing gaps in the previous studies and handle the process of HBIM and HGIS generation, respectively.

The user experience in relation to the conservation of historic buildings is the subject of the requirements in this section. In order to capture and visualize historic monuments, the needs of the Architecture, Engineering, Construction, and Owner/Operator (AECO) industries were taken into consideration when defining these requirements. It was essential to integrate Historic Geographic Information Systems (HGIS) with Historic Building Information Modelling (HBIM) in order to accurately incorporate textural features, architectural elements, structural elements, and GIS elements without requiring significant adjustments or revisions. The primary goal was to create a working prototype of a virtual environment that offers users engaging with historical models an immersive and interactive experience.

3.5 Summary

The surveying literature revealed that though those studies used specified approaches that constantly gained the highest levels of accuracy, we did not find many of them discussing in detail the historic site of Jeddah. However, most of their techniques were limited, e.g., BIM/GIS or other tools integrated with immersive technologies. We extend the adoption of all the available immersive and interactive technologies, as explained in the next chapters, respectively.

The differentiation between this present study and the others is that this study develops a pipeline for the integration of all these techniques used by others for the first time to be applied to SAUDI. Among these previous studies, a study carried out by Günay (2022) used virtual reality; Ma (2021) extended 3D-GIS district models and BIM-based building models into a computer gaming environment; and Baik (2021) used interactive virtual BIM to boost virtual tourism in heritage sites in historic Jeddah. However these studies never integrated HBIM, HGIS, interactive, and immersive technologies.

Chapter 4 : HBIM and HGIS Generation

4.1 Introduction

In this chapter, we discuss the gaps in the literature and the process of producing HBIM and HGIS from the collected data.

4.1.1 "H" in HBIM and HGIS:

In Historical Geographical Information Systems (HGIS) and Historical Building Information Modelling (HBIM), the letter "H" stands for "historic." This sets them apart from their more general equivalents, GIS (Geographic Information System) and BIM (Building Information Modelling). Here, historical structures and the vital job of heritage protection are the main topics of discussion.

4.1.2 HBIM: Capturing the Essence of Historic Buildings

By adding the architectural elements of historic structures, HBIM goes beyond regular BIM. This covers the building's non-geometric features as well as its physical geometry, such as its construction materials, historical documents, and previous modifications. Research and preservation initiatives greatly benefit from the precise and comprehensive digital representation of the building that HBIM produces by capturing this rich tapestry of data.

4.1.3 HGIS: Mapping History's Geographical Footprint

The spatial arrangement and placement of historical structures and buildings are the main topics of HGIS. Envision a map where time has been added to it. Researchers and conservationists can comprehend the historical context of these structures because to HGIS's integration of this crucial data.

4.1.4 The Power of Integration: HBIM and HGIS Working Together

Researchers and conservationists can better understand how architectural heritage has changed over time by combining the advantages of HBIM and HGIS. A larger audience can more easily study and appreciate historical structures thanks to this integrated approach, which also improves their digital accessibility.

4.2 Gaps

From investigating the literature, we found that most of the studies conducted in architecture reflected a specific understanding of individuals and objects as discrete entities that interact in various manners, such as passive and unilateral. However, such dominant dualist comprehension resulted in a critical reason for the term "implementation gap," in particular between architectural practice and research (Franz, 1994; AboWardah, 2020).

Critically speaking, the previous chapter stated the existence of a lot of gaps, which may lead to miserable or even inaccurate results. Some of the existing studies in the literature implemented significant methodological techniques that have been applied to different countries and different cultural heritages. Bakri et al. (2012) investigated the case of Bukit Jugra in Selangor, Malaysia; Ferrari & Medici (2017) conducted a study on Geguti Palace in Kutaisi; Vacca et al. (2018) applied to The Gran Torre of Oristano, Italy; Fadli & AlSaeed (2019) used the case study of Qatar. However, few references exist in the literature regarding the case of the historic heritage of Jeddah Sites in the Kingdom of Saudi Arabia, which is the main choice of the recent study (Alitany, 2014; Baik et al., 2015; Ibrahim, 2018).

Moreover, there is another gap in the literature linked to the selected methodologies by the previous researchers to cope with the process of heritage conservation, whereas they built their methodologies on a specified conceptual model or two when handling the integration of GIS with BIM. Additionally, the architecture researchers adopted convenient methods according to their specified research questions (Groat & Wang, 2002; Ozturk & Ozen, 2020). In line with that, some of the previous studies adopted integrating BIM/GIS, either solely or via generating them with other tools (the technique of integrating HBIM/GIS (Dore & Murphy, 2012; Vacca et al., 2018); the methodology of generating 3D/HBIM (Chiabrando et al., 2016); the adoption of integrating BIM/Virtual Tools (Ozcan-Deniz, 2019); and the technique of generating HBIM/Virtual Tools (Osello et al., 2018; Vacca et al., 2018).

While we appreciate the aforesaid studies and their efforts made for the sake of conservation, we have a different attitude. We think that there is still a need to integrate other technical tools for the process of heritage conservation to provide rich and valuable results. Our study is vital since it is tested and applied to a specified geographical location with the intent of creating an immersive environment for the conservation of architectural heritage. Consequently, while we are building our conceptual framework and models on the findings of these studies, we go ahead and suggest a new, novel integrated approach between HBIM and HGIS with interactive user experience as an attempt to close such gaps. In other words, the matter needs developing and instituting a significant framework to address the issues of architecture research and suggest solutions.

Pointing out the gaps in the dissertation, the previous sections identified the lack of studies applying integrated techniques for the conservation of Jeddah's historic site, by which these integrated techniques are intended to include science, knowledge, or technical development, respectively. Through the results and recommendations that emerge from this thesis, the scope of studies of this type may be expanded in the future in historical places and cities inside and outside the Kingdom of Saudi Arabia.

4.3 Stakeholders involved in the integration between HBIM and HGIS

A wide range of stakeholders can benefit from the useful data provided by this research project (Figure 4.1), which combines historical building information modelling (HBIM) and historical geographic information system (HGIS) technology. The combined HBIM/HGIS method first generates a wealth of data. It can be used by researchers to examine how buildings have changed throughout time in relation to their physical and cultural environments. Second, conservationists who not only record historic buildings but also offer advice on how to preserve them for the long run and employ efficient preservation techniques. Furthermore, the integration of HGIS enables effective oversight and administration of these locations.

Additionally, local communities that showcase the architectural history and cultural character of the city. By using the produced data to better understand their cultural origins, local communities with a stake in maintaining this legacy can build a sense of pride and ownership. By drawing tourists and raising awareness of the community's historical assets, the project can also support the local economy and cultural identity.

Additionally, IT professionals that use both proprietary and open-source HBIM/HGIS technologies fall under this category. The information will also be helpful to researchers, conservationists, documentarians, and professionals working in the field of archaeology.

Decision-Makers working on restoration projects can also use the data to help them make well-informed judgments. The information is essential for the work of professionals in conservation, architectural specialists, and data managers for historic buildings.

The project's data and applications will also be very helpful to Cultural assets Authorities, who are in charge of protecting cultural assets. Lastly, important players include researchers, developers, practitioners, and digital specialists in the fields of 3D modelling, virtual reconstructions, BIM software, GIS technology, and data integration.

This all-encompassing strategy guarantees that the project's advantages are felt by a wide variety of stakeholders, encouraging teamwork in the pursuit of comprehending, protecting, and appreciating our architectural legacy.

Figure 4.1: Stakeholders involved in the integration between HBIM and HGIS

4.4 HBIM and HGIS Production from Original Collected Data - Requirements and Issues

For the generation of the virtual environment, a 3D model of the site is required. The first step is the creation of the HBIM, which is a CAD model extraction from the collected data. It enables the parametric and procedural modeling of historic objects and buildings from photogrammetric or laser scan survey data (Dore & Murphy, 2012). HBIM includes BIM software and a semi-automatic system for plotting these objects against photogrammetric survey and/or laser scan data. The next step will be the generation of GIS information that includes non-architectural information such as vector datasets (**location**), raster datasets (**land cover imagery**), and landscape attribute data.

4.5 HBIM Generation from Field Collected Data

In this proposed work, a workflow is created to encompass the two methods used to produce point clouds: Close Range Photogrammetry (CRP) and Terrestrial Laser Scanning (TLS). Besides that, to increase geometric accuracy, traditional survey techniques will be combined to produce a georeferenced database. Figure 4.2 illustrates the proposed design.

The author integrated HBIM and HGIS systems to ensure seamless data exchange and spatial alignment. To be more specific, the data has been created using point clouds during the fieldwork. Also, utilizing the equipment provided to the author by King Abdulaziz University, such as the Leica ScanStation C10 and Leica SmartWorx Viva station (Figure 4.3), to update the outdated and inaccurate data that received from Masaken Engineering Consulting Office (2D CAD drawings (DWG)) and the Municipality of Jeddah (2D Geospatial vector layers (SHP)) for the Jeddah Historical District. Based on this updated data, HBIM and HGIS models have been created.

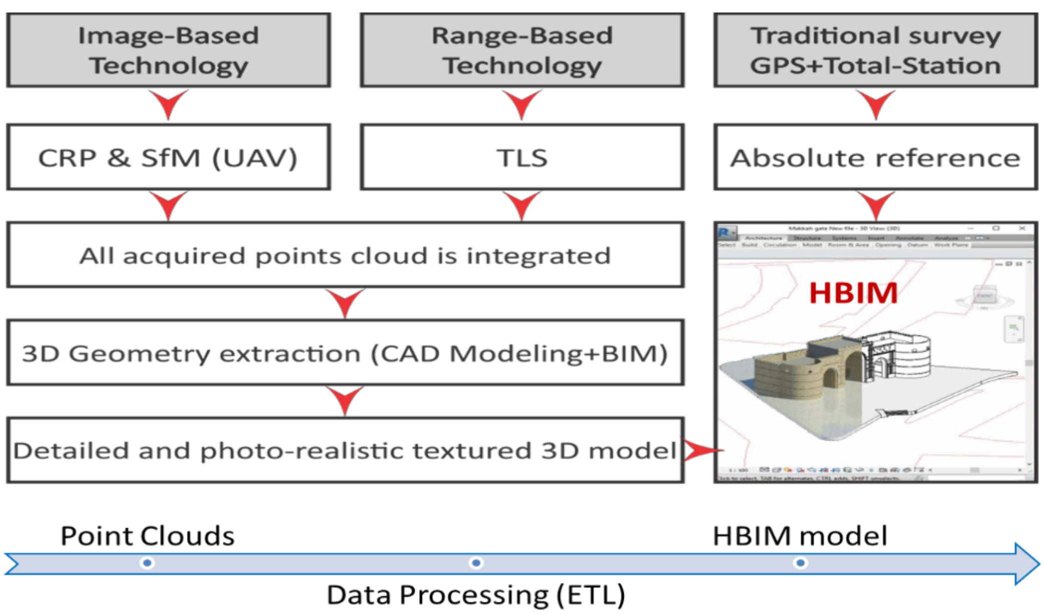

Figure 4.2: Overall Research Design for HBIM Modeling

Figure 4.3: Data collected by the researcher from the field surveying work

As explained previously, the emphasis was on updating and correcting the data as shown in Table 4.1 by utilizing the most recent technical tools and investigating historical data that was acquired from an engineering centre and Jeddah City Centre. We particularly developed a semantic data model that uses entities, categories, and interrelationships to define data integration. The data's rich model for building a digital record system of documents and analysis tools is what gives it value and utility. Stakeholders including architects, engineers, historians, restorers, archaeologists, researchers, and students can access and share the data.

Authorized people or groups involved in the management and conservation of the historic site may make updates to the data. The establishment of this historical database, which aids in the preservation and recording of Saudi Arabia's Jeddah Historic Site, is a significant contribution from this dissertation, it is noteworthy. The data can be examined and used to build corporate information systems for cultural heritage authority. The data contains material, historic, architectural, and geospatial and geo-localized data. Through the use of maps and GIS technology, it may help with understanding the cultural and ecological assets of historic sites, analyze issues related to urban and landscape conservation, and facilitate communication and information exchange.

4.5.1 Data Acquisitions

The following Table 4.1 summarizes the data used in constructing the HBIM-HGIS model. The data was provided by different consulting firms as well as the data collected from our field surveying work.

Table 4.1: The Summary of the Data used in Constructing the HBIS-HGIS Model

Item	Data Type	File Name	Description	Data Custodian	Size	Creation Date
1	2D CAD drawing (DWG)	Historic Jeddah coordinates with contour lines submitted	It contains georeferenced information such as a) Streets curbs b) Buildings footprints	Masaken Engineering Consulting Office	30.10 MB	2007
2	2D Geospatial vector layers (SHP)	GIS data	Georeferenced information such as a) StreetCenterLine b) MasterPlan c) Coastline d) Sea e) Province	Municipality of Jeddah	33.5 GB	2009-2010
3	Point clouds (PTS)	Jeddah historic monuments	Georeferenced point clouds for 5 buildings: a) Banaja Building b) Almadina Gate c) Sharif Gate d) Makkah Gate e) Alshafi Minaret	KAU / Field work	21.9 GB	2014-2016

The 2D CAD data provided by Masaken Engineering Consulting (KSA) featured two layers: street curbs and building footprints. The layers were integrated with other data sources to enrich the final model for the historic area, as shown in Table 4.1. The study used 2D geospatial vector data represented in shapefile format (StreetCenterLine, MasterPlan, Coastline, Sea, and Province) representing the historic district of Jeddah obtained from the municipality of Jeddah.

These files are updated after being co-registered and corrected. Consequently, they are used to generate a georeferenced architectural database by creating a Historic Geospatial Information System (HGIS) data model to be integrated with HBIM and complimented for interactive user experience providing highly descriptive models corresponding to the complexity of geometrical and non-geometrical aspects.

The Point clouds data collection that used a combined technique between LiDAR and Photogrammetry was conducted on all five historic monuments using a Leica ScanStation C10 device. The device was configured with a wide field of view of 360 degrees horizontally × 270 degrees vertically, and a pulse repetition rate of up to 50,000 pts/s, with a 3D scan precision of between 2 to 6 mm/50 m. The data was processed using Cyclone software to process and register the collected point cloud data.

4.5.2 Integration of Data Acquisition Methods and Generation of 3D Models

In the first phase of this proposed work, three methods are used namely, CRP, TLS, and surveying technologies as needed, to obtain georeferenced 3D models. The suitable integration of the georeferenced point clouds to model the most accurate 3D model requires careful inspection of the acquired data and the creation of a suitable workflow.

Regarding the general workflow, we followed these steps;

1. Data collection and processing for the integrated methods were carried out.
2. The survey data from this site was obtained using traditional surveying procedures.

3. It was used as a reference to assess the accuracy of the 3D model generated from TLS techniques.

4. The collected data was used to create CAD drawings extracted from point clouds.

5. As a result, historic building information modeling HBIM was generated (Figure 4.4).

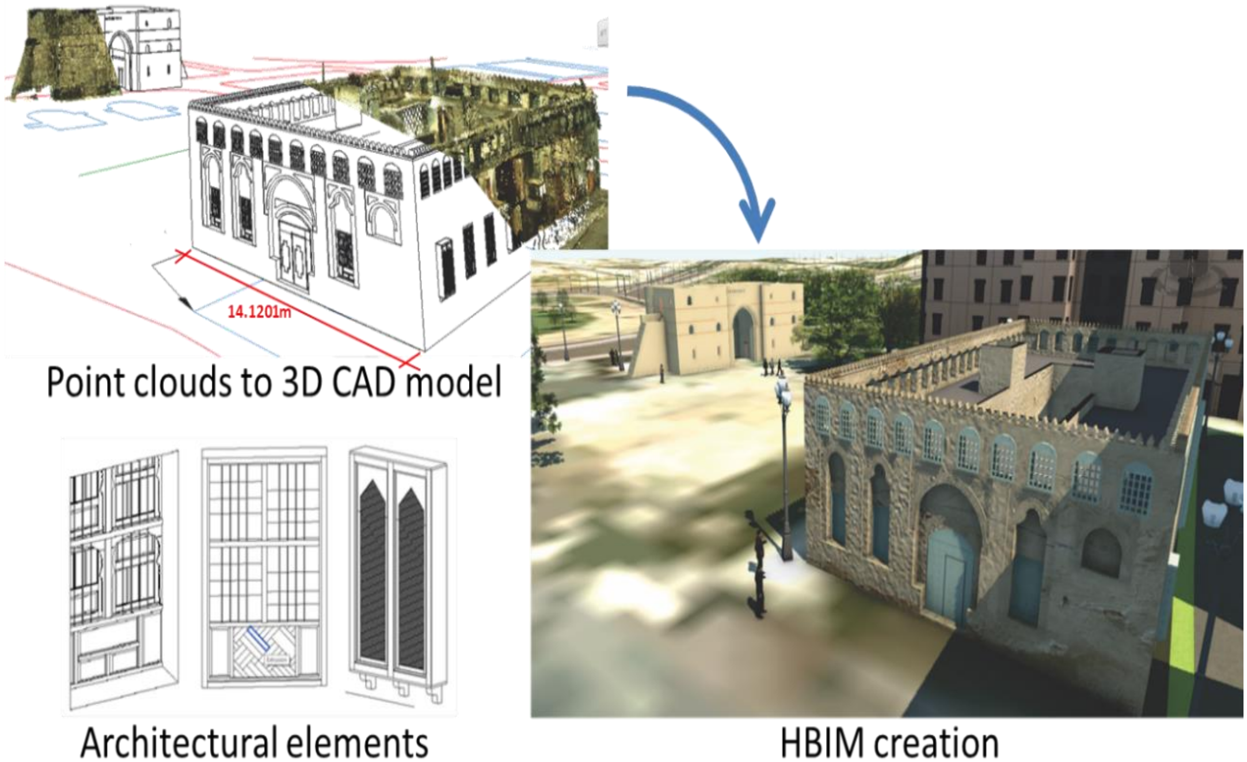

Figure 4.4: An Output Example of HBIM Generation

In the past, heritage documentation mainly relied on human interpretation and record keeping, such as hand drawings, on-site measurements, and sculptures. Laser scanning and digital photogrammetry are the two measurement techniques trending in the field of heritage conservation. Photogrammetry offers a rapidly accurate method for acquiring three-dimensional data. Data processing platforms, such as PhotoModeler, can be used to extract accurate measurements and three-dimension models from multiple photographs (Haddad & Akasheh, 2005; Jiang & Miao, 2011; PhotoModeler Tutorial, 2013).

Furthermore, laser scanners are used intensively for the generation of three-dimensional models in many diverse areas, including monitoring, navigation, and space exploration. Gathering measurement data using multi-sensors could help in data collection on heritage sites. Various studies integrate the use of laser scanning techniques and digital close-range photogrammetry to enhance the quality of the data acquired (Remondino, 2011).

The construction of Building Information Models (BIM) and the necessary 3D accuracy are covered in the dissertation. The reference points recorded by the Leica SmartWorx Viva station are compared with the results of the lidar and photogrammetric techniques. CRP, TLS, and surveying technologies are the three types of methodologies employed in the first phase of the proposed study to create georeferenced 3D models. Cyclone software is used to process and register the point cloud data after it has been collected. One of the measurement methods for heritage conservation discussed is the lidar approach, which makes use of laser scanning. It provides a quick and accurate way to get three-dimensional data.

However, another measurement method that is popular in the field of heritage conservation is digital photogrammetry. It entails taking many photos and utilizing programs like PhotoModeler to extract precise measurements and three-dimensional models.

The survey data acquired using conventional surveying techniques is used as a reference to evaluate the accuracy of the lidar and photogrammetric methods with the reference points recorded by the Leica SmartWorx Viva station. This makes it possible to evaluate the 3D model's accuracy that was produced using TLS procedures. Historic building information modelling

(HBIM) is produced by using the gathered data to produce CAD drawings that are taken from point clouds.

To sum up, the dissertation examines the accuracy of lidar and photogrammetric techniques used in building BIMs and contrasts them with reference points recorded by total stations. While digital photogrammetry offers a different method for obtaining precise measurements and three-dimensional models from many images, the lidar method offers a quick and accurate way to obtain three-dimensional data. By contrasting these methods with the reference points acquired through conventional surveying procedures, the accuracy of these methods is evaluated. The application and amount of detail required determine the necessary 3D accuracies for BIM development. To evaluate accuracy, Leica SmartWorx Viva station-captured reference points are compared to photogrammetric and lidar techniques.

4.5.3 Generation of Architectural 3D Elements

To generate the architectural elements of the created 3D window model *'Shobak'* (Figure 4.5), it is required to identify and categorize the different architectural elements of the site. For example, the typical historic buildings of the area have distinguishable features, such as:

i. Typical wooden windows, '*Roshans*' (large projecting three-sided wooden structure).

ii. Carved and ornamental doors (mostly used for the entrances).

iii. Creative forms of latticework and fretted decorations such as *Shish or Mashrabiya*, are mostly integrated into *Roshans* Sgraffito (decorative plasterwork).

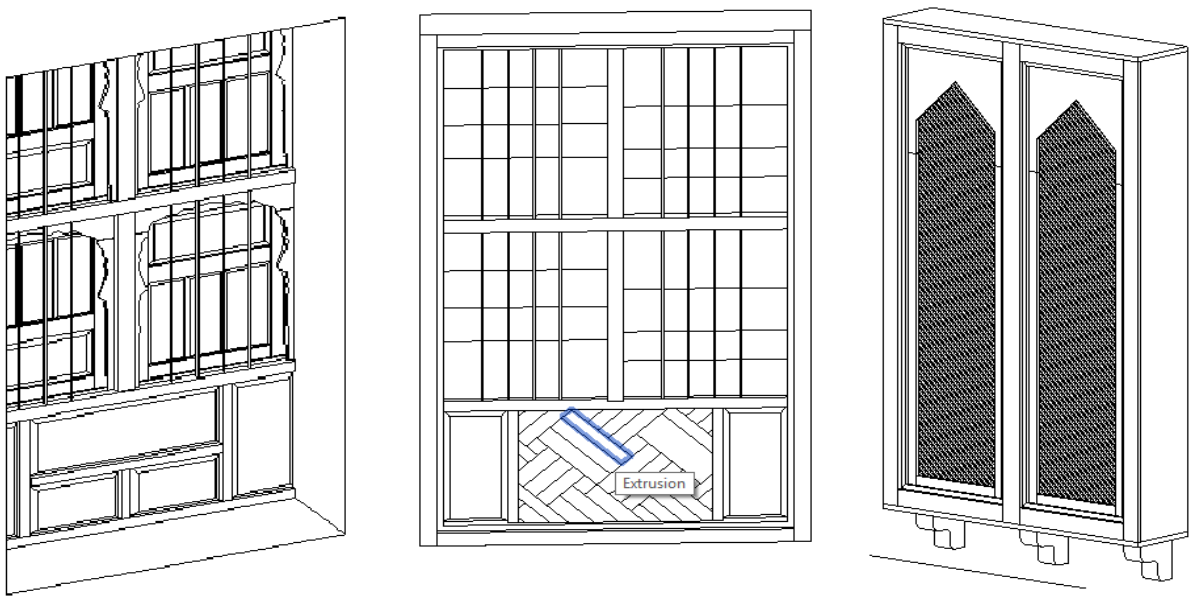

Figure 4.5: Modeling Architectural Wooden Windows Elements

The proposed 3D architectural elements involve such features, properly categorized and structured. We investigated these elements and their histories, to provide valuable information about them and facilitate future research and studies on the evolution of heritage. Furthermore, the 3D architectural elements can be used as a reference point for the required reconstruction and model refinement missions while supporting the designers to work with historic movies, games, and educational applications. In addition, while there is an absence of the architectural database of the traditional "Hijazi" architectural elements, we had to establish them.

4.5.3.1 Data Collections for the Bab Makkah Buildings

Data collection and processing using CRP and TLS were carried out for 3D modeling using one of the 15th-century cultural heritage monuments (*Bab Makkah* or Makkah gate) located in the historic district of Jeddah city, which was listed as a UNESCO World Heritage site in 2014.

Traditional land surveying with a Leica SmartWorx Viva was used as a reference to assess the accuracy of the 3D model generated from both the CRP and TLS techniques. Figure 4.6 shows the general workflow for CRP, TLS, and traditional survey work.

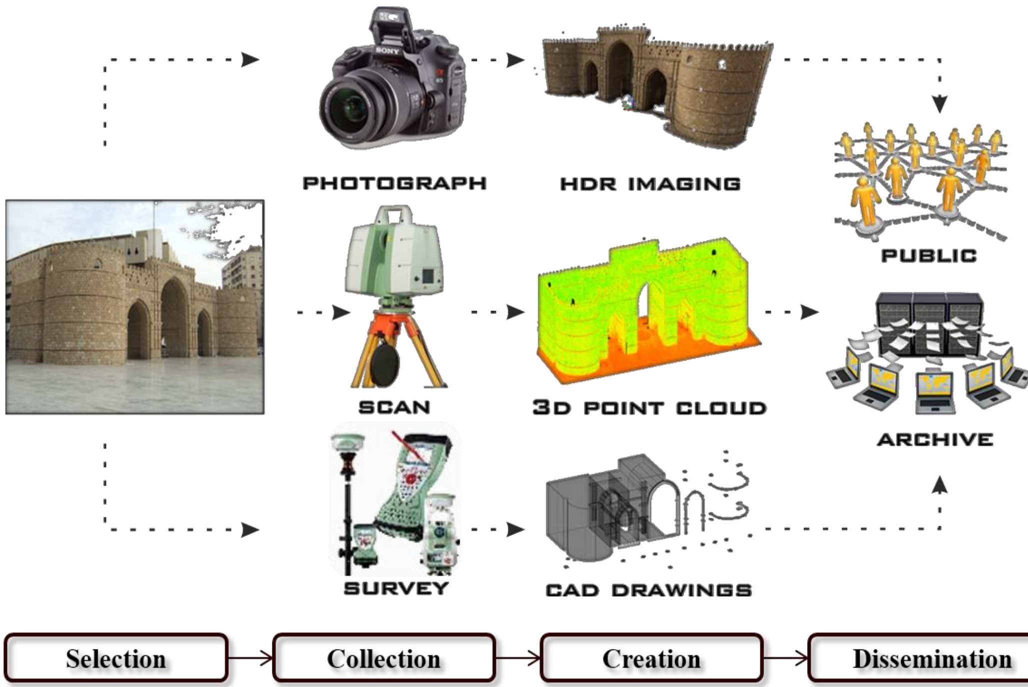

Figure 4.6: General Workflow of Data Collection

Twenty artificial black and white targets, which were placed on the facade of the gate (Figure 4.7), were used for accuracy assessment. The Leica SmartWorx Viva (LSV) was used to collect the 20 target points installed on Bab Makkah to assess the accuracy of the same points collected by CRP and TLS (Albourae, 2014), whereas the Root Mean Square Error (RMSE) was computed between these two methods. Traditional scanning techniques and CRP/TLS both need the use of point coordinates, but they differ in measuring technology, precision, data coverage and density, processing requirements, and cost. The decision between these technologies is determined by the project needs, financial limits, and desired level of detail and accuracy.

It is mentioned that the difference between the points derived from CRP (Close-Range Photogrammetry) and TLS (Terrestrial Laser Scanning) techniques compared to the point coordinates determined by traditional surveying methods is evaluated to assess accuracy. This evaluation serves as the baseline data for comparing the accuracy of the 3D models generated using CRP and TLS techniques. The RMS errors and maximum/minimum errors in X, Y, and Z directions are calculated to quantify the discrepancies between the different measurement methods. The comparison of these errors helps in understanding the geometric quality and accuracy of the 3D models generated through CRP and TLS techniques in relation to traditional surveying methods.

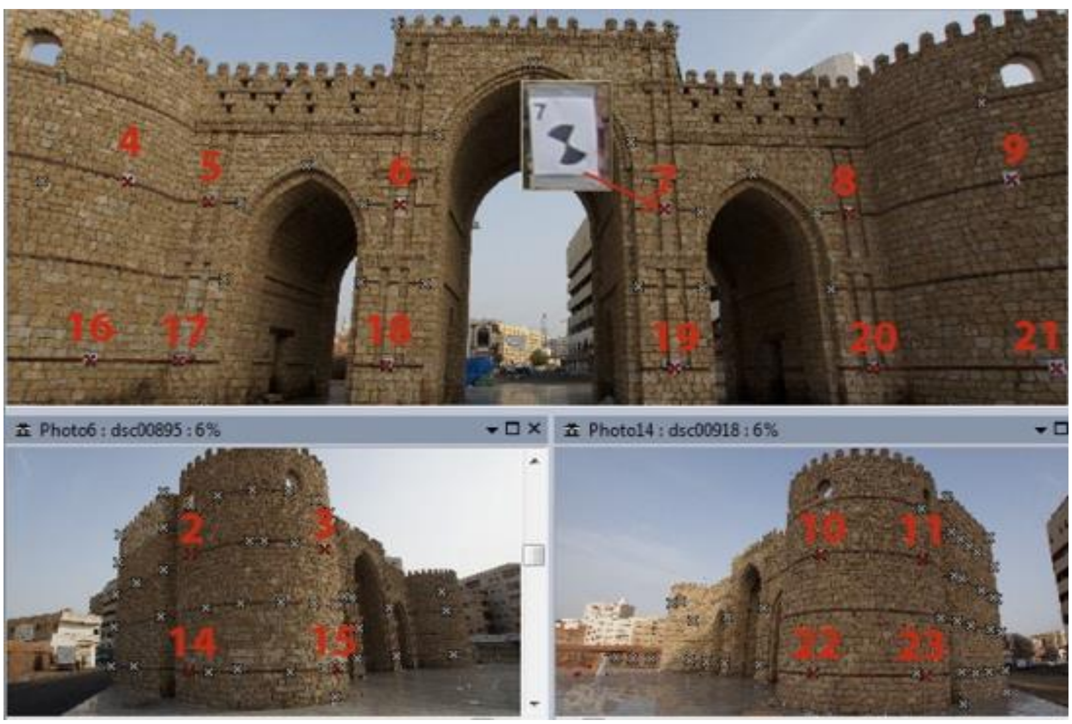

Figure 4.7: The Distribution of 20 Artificial Black and White Targets on Bab Makkah

RMSE is a normally used measure of the differences between values predicted by a model and the values observed. The measurements are given to those targeted points due to the unavailability of authorized 3D CAD drawings for Bab Makkah, which can be utilized as reference data to assess accuracy. Figure 4.8 illustrates the concept of data acquisition for Bab Makkah using the LSV. The LSV was set up in front of the gate in a position marked as “station P1” while another backside station was set up as “station P2”. Since the LSV was equipped with GPS, the coordination of these two points could be obtained in a global coordinate system (WGS-84). In this case, a baseline was setup, and the 3D coordinates of the target points positioned on the Makkah gate could be surveyed with absolute coordinates. The absolute coordinates specify the exact location of specific points on the Earth's surface relative to the equator and prime meridian. such as WGS-84 for GPS coordinates. By using absolute coordinates, it provides a standardized and globally understood way to represent the location, enabling accurate measurement, mapping, and modeling for spatial analysis.

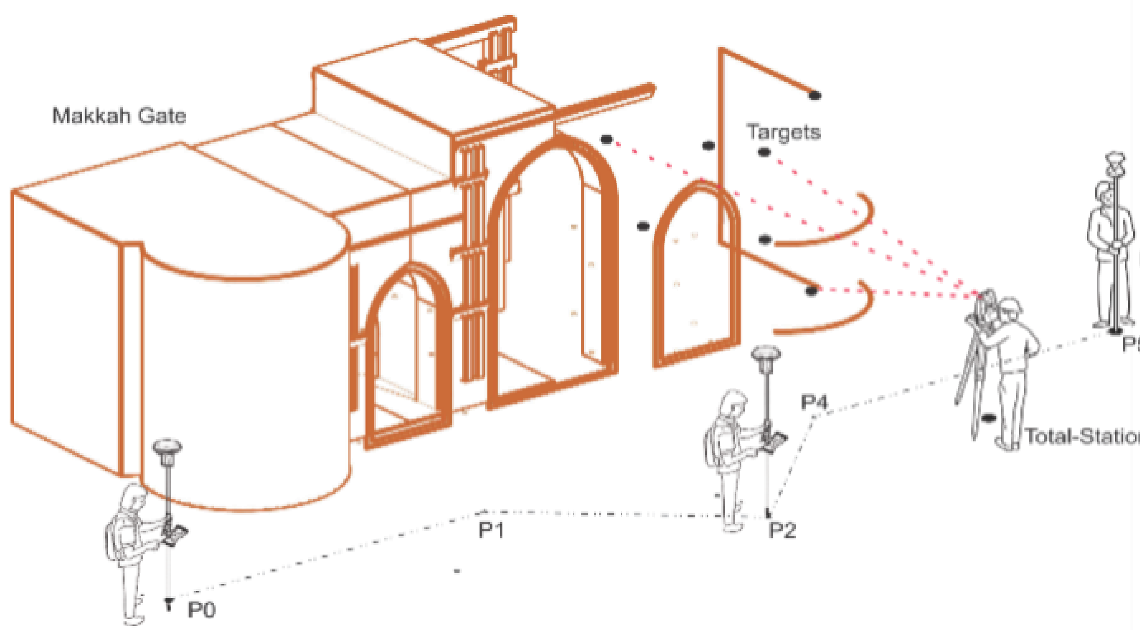

Figure 4.8: An Illustration of Traditional Survey Methods using Leica SmartWorx Viva

Finally, the twenty artificial targeted points were collected for Bab Makkah, to assess accuracy. It is worth mentioning that these twenty target points are evenly distributed within the structure and located at different parts of the structure, to be used later in the process of assessing the accuracy of the target points measured by TLS and CRP. The findings will be explained in detail in Chapter 5.

4.5.3.2 Accuracy Assessment of Bab Makkah's Results

The findings show that both CRP and TLS techniques can achieve accurate results similar to traditional surveying techniques. Generally, it was found that TLS offered better results, compared to CRP with respect to the land surveying method using the Leica SmartWorx Viva (LSV) station.

As shown in Appendix I, ten of the target points are located in the lower portion of the structure (approximately 5 m above the measurement datum), and the other half of the 20 points are located in the upper portion (approximately 10m above the measurement datum) of Bab Makkah. The RMSE using the CRP technique of the control points are 0.015m, 0.047m, and 0.007m in X, Y, and Z directions, respectively.

Results also show that the minimum errors of X, Y, and Z are 0.0m, 0.003m, and 0.0m, respectively while the maximum error reaches 0.036m, 0.081m, and 0.014m in the X, Y, and Z directions (as shown in Appendix II). The minimum RMSE of all the points is 0.007 m where the maximum RMSE reaches up to 0.047 m, resulting in an overall RMSE of 0.043 m. Noticeably, the relatively large RMSE values are found at points BW09 and BW21 (Figure 4.9 and Table 4.2), on the right side of the main entrance of Bab Makkah. Due to the low contrast of photos taken at this portion, we can achieve a relatively low number of matching points in this curvy area. This situation degrades the geometric quality of the generated 3D model, resulting in a relatively high RMSE in the Y direction close to 0.081m.

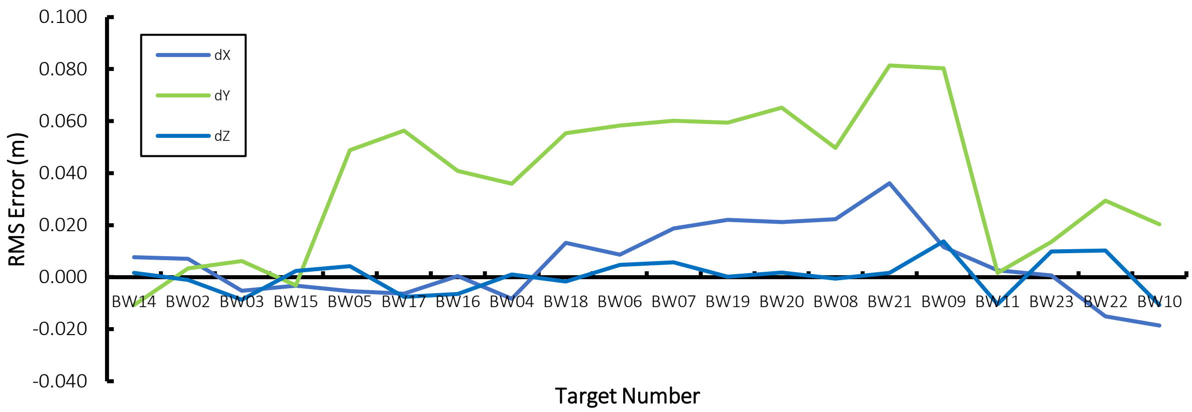

Figure 4.9: The RMS Error Produced by The CRP Technique compared to the land surveying method

Table 4.2: A summary of the accuracy assessment of CRP compared to the land surveying method

	CRP (m)			
	dX	**dY**	**dZ**	
Min error	**0.0**	**0.003**	**0.0**	
Max error	**0.036**	**0.081**	**0.014**	
Average error	**0.012**	**0.039**	**0.005**	
All RMSe	**0.015**	**0.047**	**0.007**	**0.043**

Appendix II shows the same 20 points measured by the LSV and TLS. The RMS errors of the target point residuals are 0.014 m, 0.009 m, and 0.001 m in the X, Y, and Z directions, respectively.

Results also show that the minimum error using the TLS for Bab Makkah in X, Y, and Z are all close to zero while the maximum error reaches 0.029 m, 0.021 m, and 0.002 m, in X, Y, and Z directions, respectively (Figure 4.10 and Table 4.3).

Overall, the RMSE calculated at the target points is better than those obtained measured by the CRP technique. The overall RMSE is 0.011 m with a maximum RMSE of 0.029 m and a minimum RMSE of 0.0 m. Compared to the results obtained with CRP, there is no notable fluctuation of the RMSE among the 20 points.

Figure 4.10: The RMS Error Produced By The TLS Technique compared to the land surveying method

Table 4.3: A summary of the accuracy assessment of TLS compared to the land surveying method

	TLS (m)			
	dX	dY	dZ	
Min error	0.001	0.0	0.0	
Max error	0.029	0.021	0.002	
Average error	0.011	0.007	0.000	
All RMSe	0.014	0.009	0.001	0.011

In the case study of Bab Makkah, CRP and TLS produced 4.3 cm and 1.1 cm in overall RMS error. Maximum RMS errors in TLS were usually found on the object points located on the complex structure of this study site; whereas high RMS errors in CRP were observed when those object points were extracted in the low-contrast portion of the images. The minimum difference between these two methods is found at point BW15.

However, a significant difference in the RMS error is observed in points BW09 and BW21, where the difference is up to 8 cm (Figure 4.11). One should note that BW09 and BW21 are located on the curvy structure of Bab Makkah. Given that, TLS should be considered, to achieve higher accuracy, especially if the heritage structure has a large portion of irregular components.

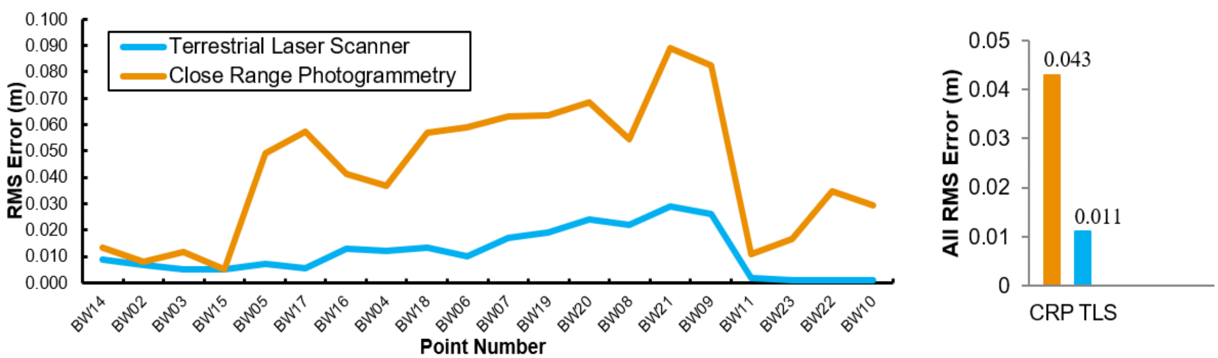

Figure 4.11: The Minimum and Maximum Differences Between the CRP and TLS Methods

Following the results of this study, heritage site recording and modeling should be conducted using both techniques. Initially, CRP can provide fruitful textural information about the surveyed sites, which can be used to produce photorealistic three-dimensional models. On the other hand, the high density of TLS point cloud data can offer an accurate detailed architectural description of the study sites, which has the capacity of providing a direct solution for heritage site rehabilitation.

These facts drive us to argue that, both techniques should be considered complementary; rather than, adversarial. Further research should investigate the implementation of an efficient and one-off solution for reality-based surveying and 3D modeling of heritage structures by using such a combination of measurement techniques.

4.6 GIS Generation from Collected Spatial Data

The data collection and processing for GIS and HGIS creation (Figure 4.12) used in this section, for enriching the HBIM model with accuracy and geospatial location information, are categorized into three groups supported by historical references. They are obtained from existing 1) geospatial (GIS) layers, 2) CAD drawings, and 3) 3D data point clouds.

The multiple data sources are used and processed through the Extract, Transform, Load (ETL) tool, to match, re-project, extract, and classify the information into the HGIS data warehouse. The rationale of integrating all these three types of data is mainly to integrate in the study all topographic features and masterplans of the historic sites from existing GIS and CAD data while the 3D data point cloud can facilitate the creation and generation of digital 3D models of the historic sites.

Not only do these data provide the geometric outlook of the area but also include any semantic information stored underneath. They are categorized based on their production workflows and their usage. The GIS layers represent the parcels defining the city, the sea limits, street centrelines, and major landmarks as well as the study area that can provide the reference frame for positioning the 3D models imported from the BIM platform.

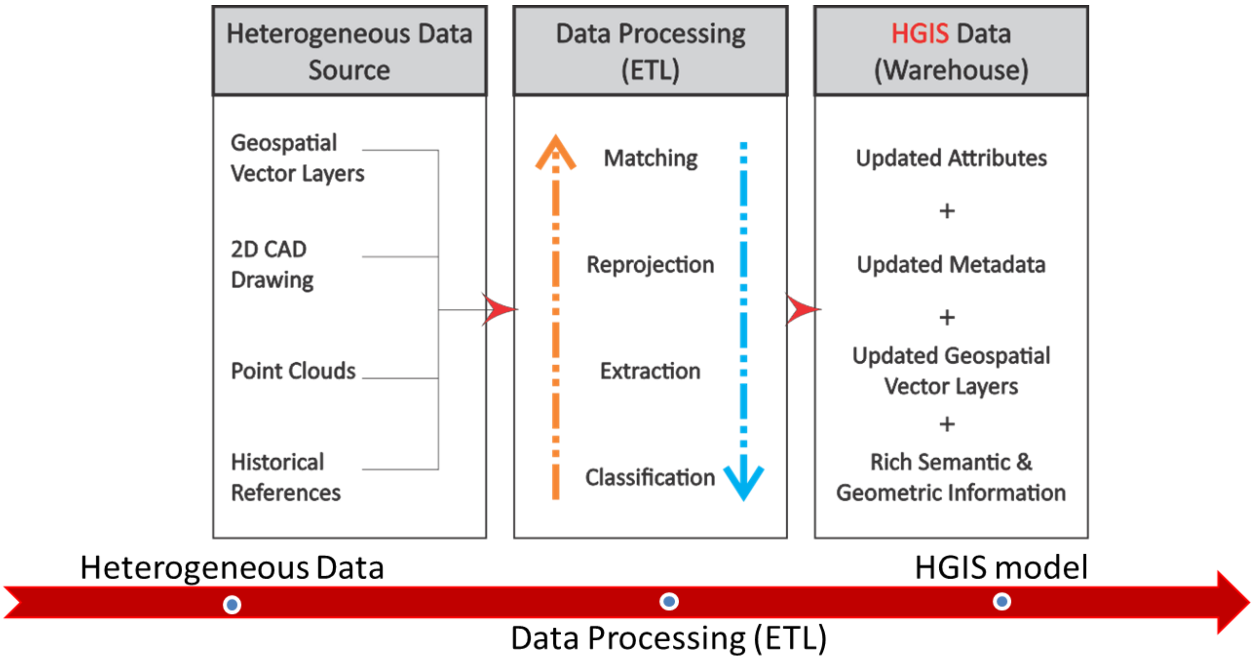

Figure 4.12: HGIS Creation and Enhancement

4.6.1 Group 1: Geospatial vector layers data representing the historic district of Jeddah collected from the municipality of Jeddah (KSA).

The various geospatial vector layers were used after they were co-registered and corrected. It was necessary to re-project and correct the Coastline and sea layers using Ain el Abd UTM Zone 37N, and MasterPlan (with unknown projection) shifted with the Province, PublicFacilities, StreetCenterLine, and StreetCurb10k layers so that they all can be aligned and projected to the WGS 1984 UTM Zone 37N reference system (Figure 4.13). Additional GIS tasks were carried out to restrict the study areas (clip, re-project, and match).

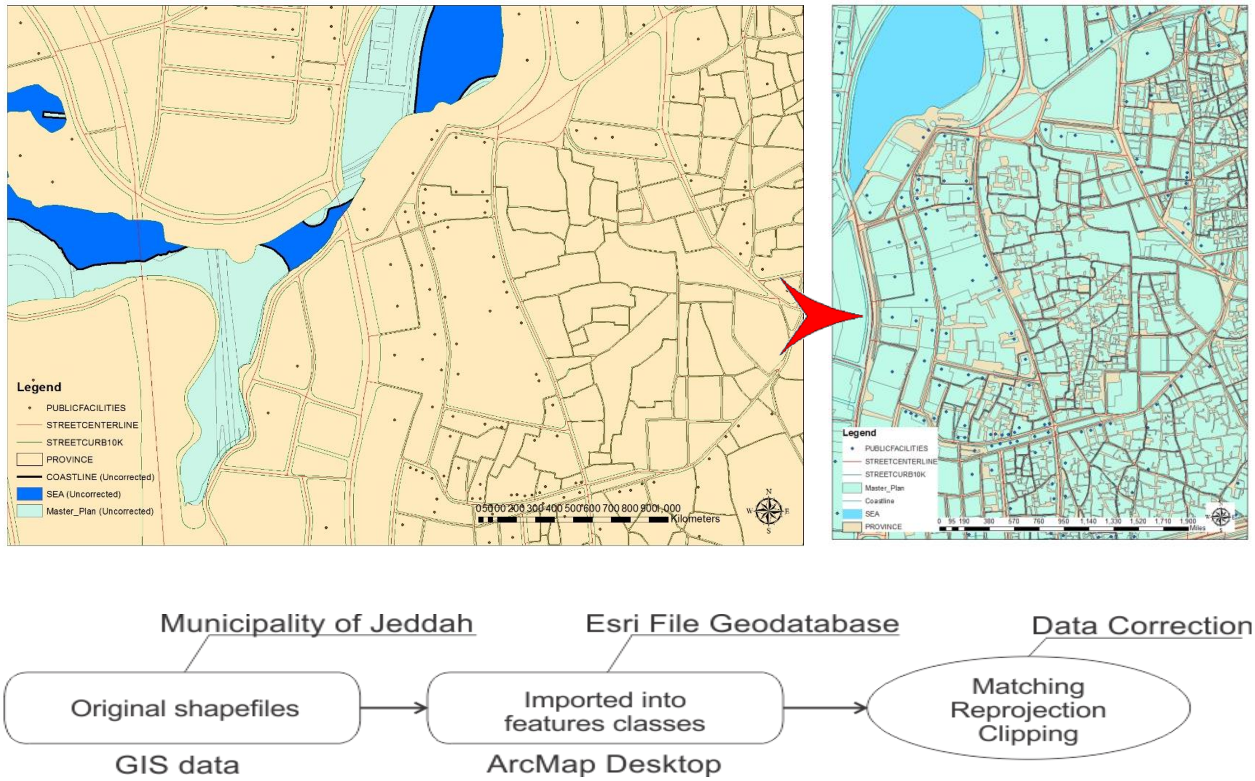

Figure 4.13: The data before and after processing

4.6.2 Group 2: CAD data provided by a consulting firm called Masaken Engineering Consulting Office.

For integration with other datasets, the AutoCAD files were subject to classification, re-projection, and editing with a schema enhancement by creating new fields to add semantic information describing the areas on the historic building. This was supported by using Matthew's 1979 classification rules (Bagader, 2016), thereby dividing Jeddah's historic buildings into three classes (national, regional, and local significant) based on their historic and architectural relevance (Figure 4.14).

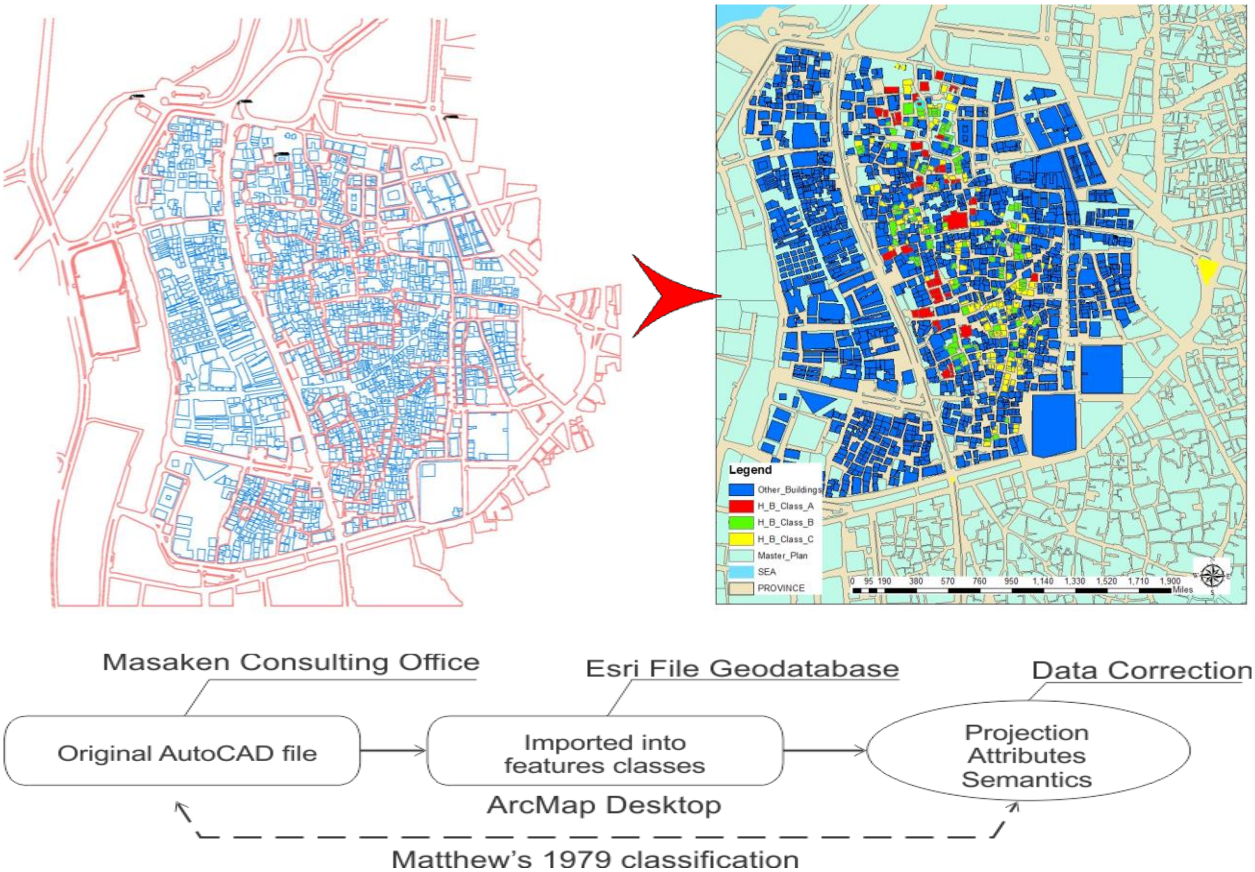

Figure 4.14: Buildings Classifications

4.6.3 Group 3: 2D HGIS Model extracted from Point Clouds provided from KAU/Fieldwork

Initially, the georeferenced point cloud data was generated from laser scanning, which was not compatible with ArcGIS without using the interoperability tool, in particular after conducting many tests. Therefore, 2D boundaries of the five chosen historic buildings (Banaja Building; Almadina Gate; Sharif Gate; Makkah Gate; and Alshafi Minaret) were extracted using the Autodesk Revit platform, and imported to AutoCAD as a DWG-type file drawing. Then, the DWG files were converted and imported into a geodatabase, and list feature classes, using FME workbench and then ArcGIS, whereas the results represented in the images of the chosen sites confirm the success of the documentation process, using 2D and 3D models in the imaging space with an accuracy comparable to the accuracy, which can be obtained from laser scanning technology. This process resulted in an enriched and updated view of these sites, as illustrated in (Figure 4.15).

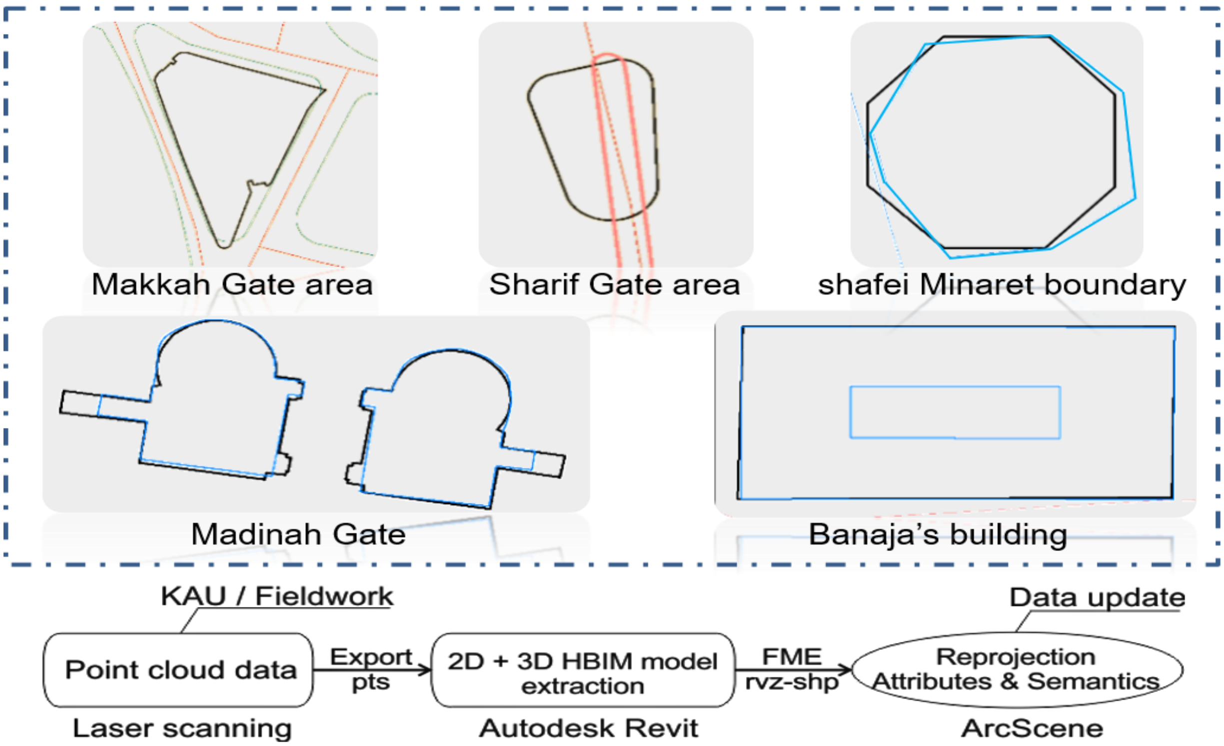

Figure 4.15: The Black Polygon represents the Accurate Boundaries of the Historic Objects

From the previous (Figure 4.15), we can comment on how well this process worked in each of the five sites.

The attributes in BIM refer to the detailed 3D visualization and the ability to organize large volumes of data on buildings. On the other hand, the attributes of GIS refer to its high customizability and its suitability for analysis and visualization of geospatial data.

Semantics in BIM (Building Information Modelling) refers to the interpretation or meaning of the data pertaining to building objects. This comprises characteristics that describe the building's physical and functional qualities, such as the materials used, its proportions, the interactions between its various construction elements, and other pertinent information. Semantics in GIS (Geographic Information System) refers to the interpretation or meaning of the spatial data. This comprises characteristics that describe the geographic context and properties of the data, such as the location, aspects of geographic features, and relationships between various geographical objects.

Consequently, the meaningful integration of the characteristics and data from both BIM and GIS is referred to as semantics in the context of BIM and GIS integration, enabling a thorough understanding and analysis of the building objects within their geographic environment.

4.7 Summary

The chapter explained the process of HBIM and HGIS generation, which in turn will lead to discuss the following point of HBIM and HGIS integration in the next chapter, significantly.

Chapter 5 : HBIM and HGIS Integration

5.1 Introduction

This chapter is specified for addressing the methodology adopted while focusing mainly on explaining the integration process between HBIM and HGIS, respectively. The following sections will include discussing the modeling and designing of the study, integration of HBIM and HGIS, conceptual HBIM-HGIS integrated model, issues of data integration between BIM and GIS, and the chosen application software. Two models of integration are proposed: HBIM and HGIS into the HGIS platform and HBIM and HGIS into a different platform system. The reason for stating both models is to strengthen the suggested methodology and to get better results in the end.

5.2 Modeling and Designing of the Study

As mentioned previously in the last chapter while conducting the process of generating BIM and GIS, we found that most of the researchers focused on special cases and a specified objective of the aimed integration or generation. Whereas on the other hand, Fosu et al. (2015) referred to some authors who attempted to establish in their studies, their approaches focusing on the integration model used, such as BIM/GIS, GIS/BIM, BIM and GIS, Unified Building Model, or Web viewing applications for the physical preservation of historic buildings. The model proposed in this research is based on constructing a semantic data model that describes data integration in terms of the types of entities or objects that exist in the target application environment, the classifications and grouping of those entities along with the structural interrelationships among them. The semantic-based model will provide a collection of high-level modeling primitives to capture the semantics of entities (attributes, metadata) by accommodating derived information in a data structure that allows the same information to be viewed in several ways and on different platforms and makes it possible to accommodate with the needs and processing requirements in the applications domain. The resulting data model will provide a rich model with benefits from both platforms to help in creating of digital records system of documents and analysis tools with the ability to add additional information using extract, transform, and load tools (ETL) workflows and heterogeneous datasets to the integrated model. The methodology workflow is illustrated in (Figure 5.1). With regards to the study's modeling, the qualitative methodology focuses on the design and implementation of a complex workflow of processing data from multiple sources, 3D modeling, management of the resulting model, and analyzing/visualization. Figure 5.2 illustrates the details of the workflow consisting of three main steps;

1- HBIM and HGIS production from originally collected data;

2- Integration of HBIM and HGIS for the creation of continuous 3D real and virtual models; and

3- Interactive immersive environment.

Critically, the steps taken, such as subdividing the modeling into parts using BIM tools for 3D modeling-based laser scanning data, and GIS data and management of the resulting models in enhancing the resulting model through editing datasets and creating metadata are illustrated. Besides, integration of the 3D HBIM model into an HGIS will be implemented for further management and analysis. Texture details are then applied to generate a highly detailed rendition of the object from different angles that can be visualized in a web application or tested in real-time, with full fidelity, using a game engine. Then, the virtual and augmented devices can be used to present the information to the user. All these points will be explained in detail in this chapter.

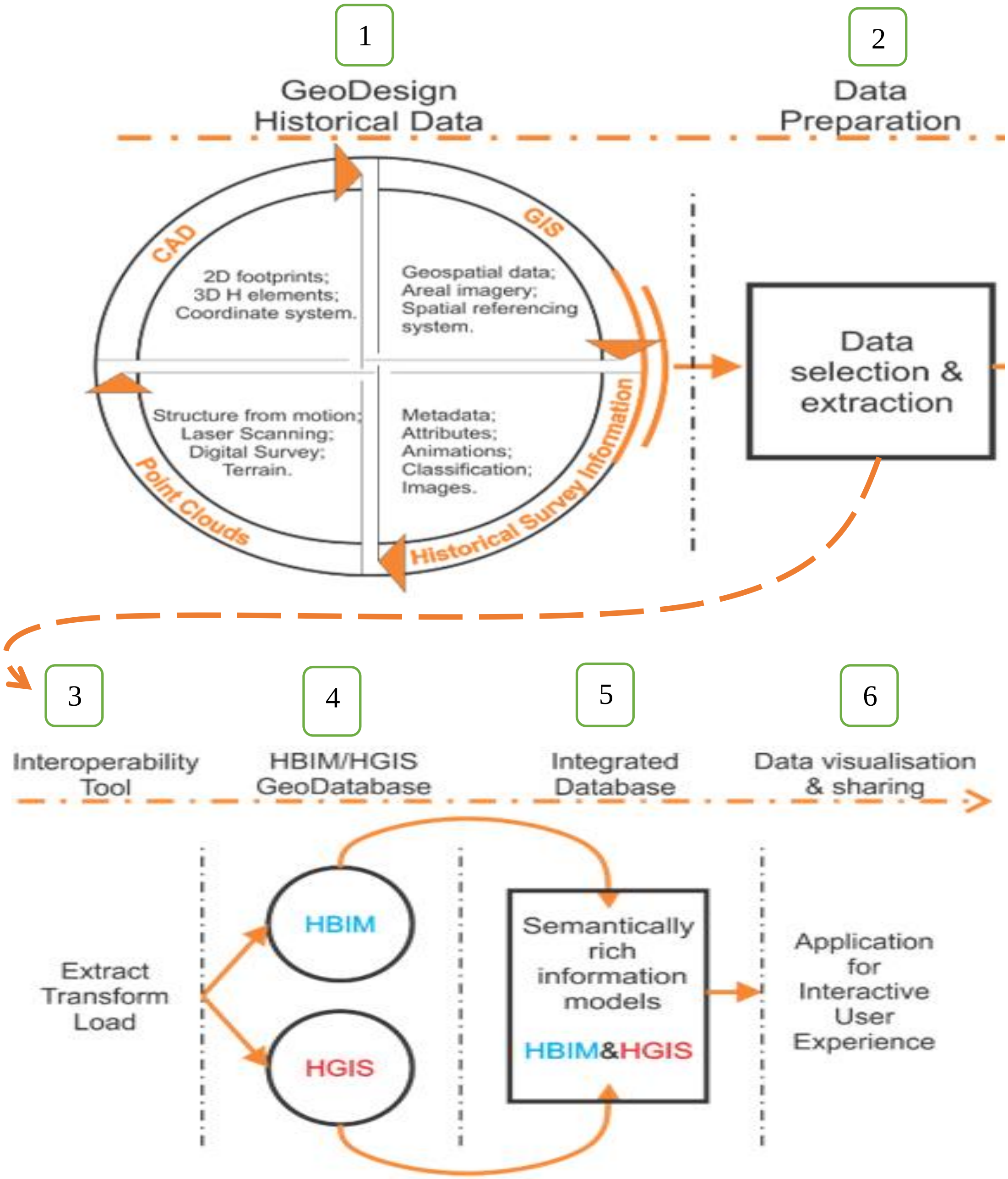

Figure 5.1: Methodology Workflow

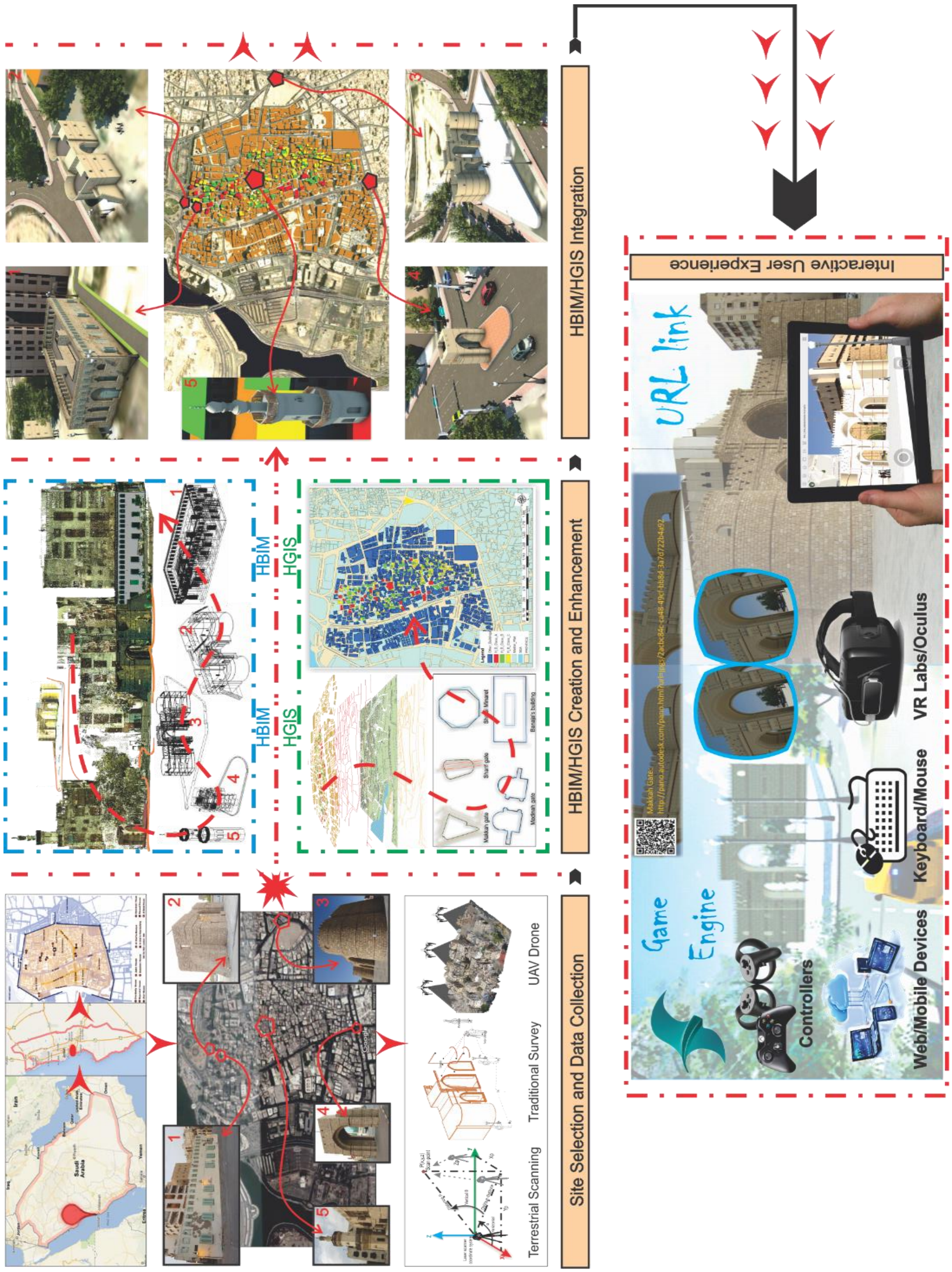

Figure 5.2: Methodology Workflow Steps

The final output will have multiple facets depending on the requirements needed, 3D models with diverse levels of details and links to contextual information. The developed model will be used for the proposed application, which will be required to feed the models into interactive platforms and collect the necessary historical and architectural information that will be useful for documentation, conservation, and tourism purposes.

These 3D elements will also be helpful for possible future applications, such as the physical reconstruction of degraded monuments, gaming designs, and educational purposes.

The historical geographic information system (HGIS) and historic building information modelling (HBIM) were integrated using a multi-step approach, according to the information obtained.

Using originally gathered field data, such as the Jeddah historical datasets, HBIM and HGIS were created in Part I. This required gathering and analyzing data from many sources in order to produce the HGIS and HBIM models.

The integration of the HBIM and HGIS models was done in Part II. In order to generate a semantically complete HBIM-HGIS model, the properties and attributes of the two models were combined during this integration process. Software that is available commercially on the shelf (COTS) was used for the integration.

An interactive environment for user experience was developed in Part III. Users could access the integrated HBIM-HGIS model after it was uploaded to a cloud-based service. Within the scene, the model supported both immersive and non-immersive inquiries.

Creating an interactive user experience environment for accessing and exploring the integrated model was one of the main tasks involved in the integration of HBIM and HGIS. The models were also generated and combined with their properties and attributes.

5.3 Integration of HBIM and HGIS

The second stage is integrating HBIM/HGIS. Generally speaking, BIM is a new standard for CAD drafting in the Architecture, Engineering, Construction, and Owner/ Operator (AECO) industries. This technology plays an important role in the design, reconstruction, and maintenance of buildings, and in managing the essential building information in a digital format throughout the building lifecycle (Succar, 2009; De Laat & Van Berlo, 2011; Amirebrahimi et al., 2015; Baik et al., 2015; Alliance, 2016; Bai, 2016).

Based on the fact that integrating BIM/GIS has many challenges at various levels, considering the differences between the two systems is a must. Generally, BIM on the first hand is centered on architectural information linked to buildings, paying attention to the importance of geometry, such as materials and dimensions. GIS, on the other hand, is centered on the spatial configuration of information such as location, and ground imagery (Bai, 2016; Choi et al., 2015; Kota et al., 2014).

Therefore, an integration of BIM and GIS capabilities, which are considered heterogeneous data sources, can provide a more detailed and clear picture of a multi-faceted project. The integration of heritage recording and BIM can document and manage historic buildings. This method takes into account historical data and layers that represent historic components of the buildings, including both non-geometric and geometric attributes and the relationships.

Settling upon that, the integration between HBIM and HGIS attempts to build a prototype of heritage architectural elements with the environment surrounding the nominated site to study and understand the evolution of the architectural heritage of the city and increase its digital accessibility, significantly. It will be helpful for possible future applications, such as the physical reconstruction of degraded monuments, gaming designs, visitors, and educational purposes.

In this study, we are proposing a new strategy for the effective integration of the historic building information model (HBIM) into a geographic information system (GIS). The implementation based on the phases will be:

Phase 1: HBIM and HGIS generation from the originally collected field data; (Data acquisition from various sources and preparation, and Data processing into appropriate formats);

Phase 2: Data integration from HBIM and HGIS;

Phase 3: Data visualization and dissemination.

As presented in the previous Chapter, the creation of a 3D model must be proceeded by data collection; currently, laser scanning and digital photogrammetry are understood as modern methods of data acquisition. The result of laser scanning is a dense point cloud, and even though this point cloud can be used for some site conservation purposes, it is hardly a full-fledged 3D model. Consequently, there are a lot of efforts that deal with the conversion of the acquired data from the point cloud into a parametric 3D model. For instance, the work of Fai et al. (2011) was focused on issues related to combining laser scanning data and 3D models from BIM modeling software. The fundamental steps in constructing the integration between HBIM and GIS are discussed. The multiple heterogeneous data from both the HBIM-GIS domains along with the steps of data collection and processing to the construction of the model are presented. In resolving conflicts and overcoming challenges within the HBIM-GIS, integration is always a crucial part of the implementation. The integration workflow complexity is described taking into consideration the characteristics and functionalities brought by both HBIM and GIS domains. HBIM and GIS use different semantic definition types, which enrich the dataset to be integrated. This research thus provides data management and advanced analysis tools for the resulting 3D HBIM-GIS integrated model. Figure 5.3 illustrates HBIM and HGIS integration and enhancement.

Figure 5.3: HBIM and HGIS Integration and Enhancement

5.3.1 HBIM-HGIS Integration into an HGIS platform

This part is subdivided into two sections that reflect the complex design workflow and take into consideration the integration of HBIM and HGIS. Both use different semantics and attributes that would enrich the dataset if integrated. To clarify semantics, It focused on meaningful interpretation and understanding of response to feedback, while attributes with subtle characteristics are concerned with data elements. In the example shown, the integration of BIM and GIS entails managing both semantic information (such as life cycle stages and historical references) and attribute data (such as geometric accuracy and descriptive details) and ensuring the usability and relevance of the deliverable set. This study facilitates data management and advanced analysis to provide a highly detailed model for the proposed application.

The objective of this task is to investigate, design, and integrate HGIS and HBIM platforms, data, and tools in applications for the information management of heritage buildings taking into consideration their cultural and natural particularities.

To achieve these objectives, we investigated heterogeneous datasets and applied different integration workflows and procedures to explore and resolve conflicts regarding geo-referencing systems, storage requirements, and data attributes and types. Due to the absence of specialists, the architectural database of the traditional “Hijazi” architectural elements does not exist digitally. Thus, establishing an architectural database is another target of this project.

The diagram of the HBIM-GIS integration workflow is summarized in (Figure 5.4). The resulting HBIM-GIS integrated model will improve combined data quality efficiency, query, and retrieval of semantic and geometrical information. Translation tools and data usage may interfere and provide a challenge for integration later, therefore our objectives are:

1. Integrating the HGIS and HBIM data;
2. Using heterogeneous datasets to explore and update data;
3. Providing rich semantic information for the dataset;
4. Establishing the "Hijazi “digital architectural database.

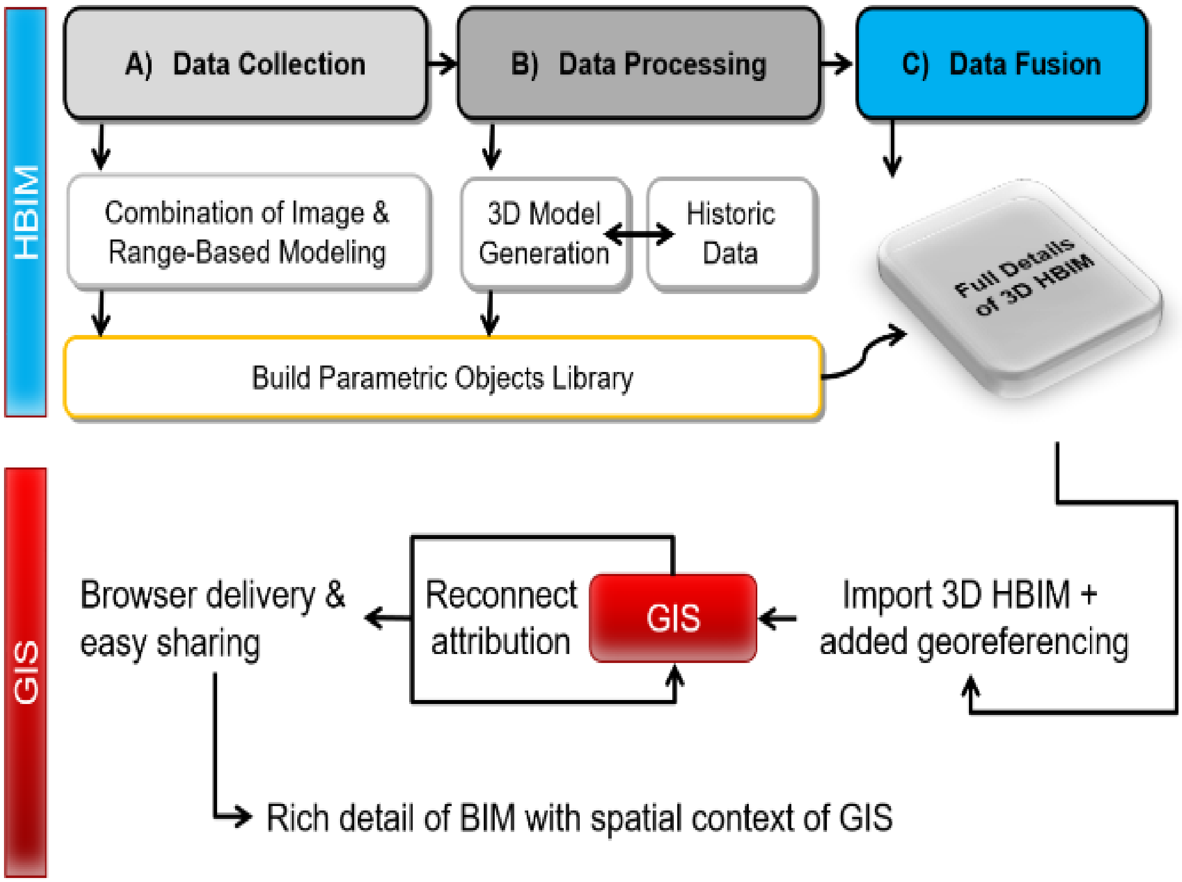

Figure 5.4: Overall Workflow of the Integration of HBIM and GIS in the GIS environment

Many spatial data manipulation toolsets from different technology platforms, such as ESRI ArcGIS for desktop, InfraWorks 360, Autodesk Revit, AutoCAD, Future Manipulation Engine (FME), and Safe Software Workbench were used during each of the phases of data preparation, cleaning validation and implementation of the integration workflow. As a result, the HBIM/HGIS database is available to the users through a single interface.

Methods of integrating HBIM/HGIS in an interactive user experience environment: In order to develop engaging and dynamic user experiences for heritage conservation and documentation, the workflow and approach that are outlined centre on the integration of historic Building Information Modelling (HBIM) and Historic Geographic Information System (HGIS).

To accomplish comparable objectives, alternative procedures and strategies are in fact feasible. To further improve the user experience, an alternate strategy might be to leverage cutting-edge data visualization methods like virtual reality (VR) and augmented reality (AR). The integration of these technologies has the potential to enhance users' immersion and engagement with the historic models, so fostering a deeper comprehension and admiration of the cultural places.

Additionally, working with professionals in domains like architecture, archeology, and cultural heritage preservation could yield insightful knowledge and experience to improve the workflow. To assure the authenticity and quality of the historical models and data, the approach could be further improved by adding other viewpoints and information.

In conclusion, even though the workflow that has been described is thorough and efficient, investigating different strategies that incorporate cutting-edge technologies, interdisciplinary teamwork, and creative approaches may present fresh opportunities for improving the conservation and recording of historical sites.

5.3.1.1 3D HBIM extracted from Point Clouds to be hosted into GIS System

For digitizing and optimizing the processes of accurate surveying and correcting the process of management of the historic architectural heritage through the modern tools of HBIM and 3D GIS, the extraction of data and geometries have been implemented using Safe Software Feature Manipulation Engine (FME) transformers and ETLs on the given 3D historic models.

Based on that, the point cloud model of the Sharif Gate model was run into the AutoDesk Revit platform, and the Revit FME exporter plug-in was used to export the 3D model including all its attributes from Revit (*.rvt) to an extension (*.rvz) file format, to avoid losing object data (Figure 5.5). However, (*.rvt) files are the files extension to Autodesk Revit Project Files, which can be used to create 3D building models and as well as the drawing sets, while (*.rvz) files are associated with zero unique file types (Binary Data format), therefore can be viewed with the Binary Data. These files can be seen on mobile devices and desktops, which means to be found on the common devices of every user (Geater, 2022).

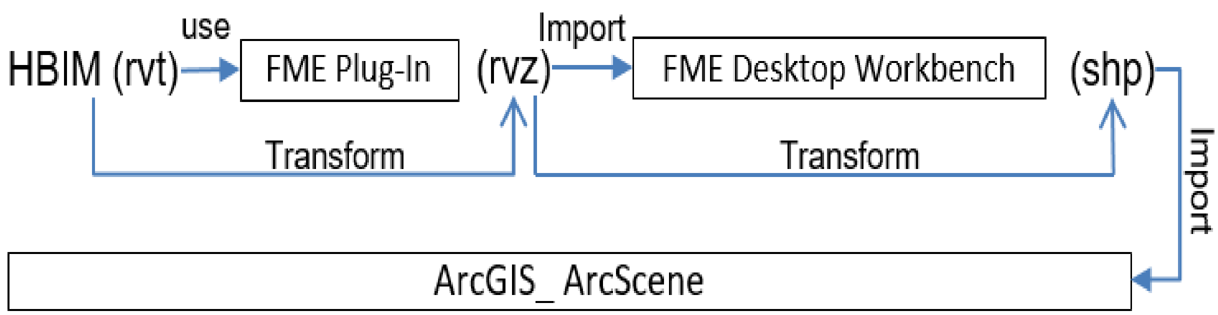

Figure 5.5: The implemented Workflow of Transforming the HBIM Model to GIS

This approach facilitates the process of creating an FME workspace to transform 3D data into geospatial vector layers that could be compatible with GIS (ArcScene program), as shown in (Figure 5.6).

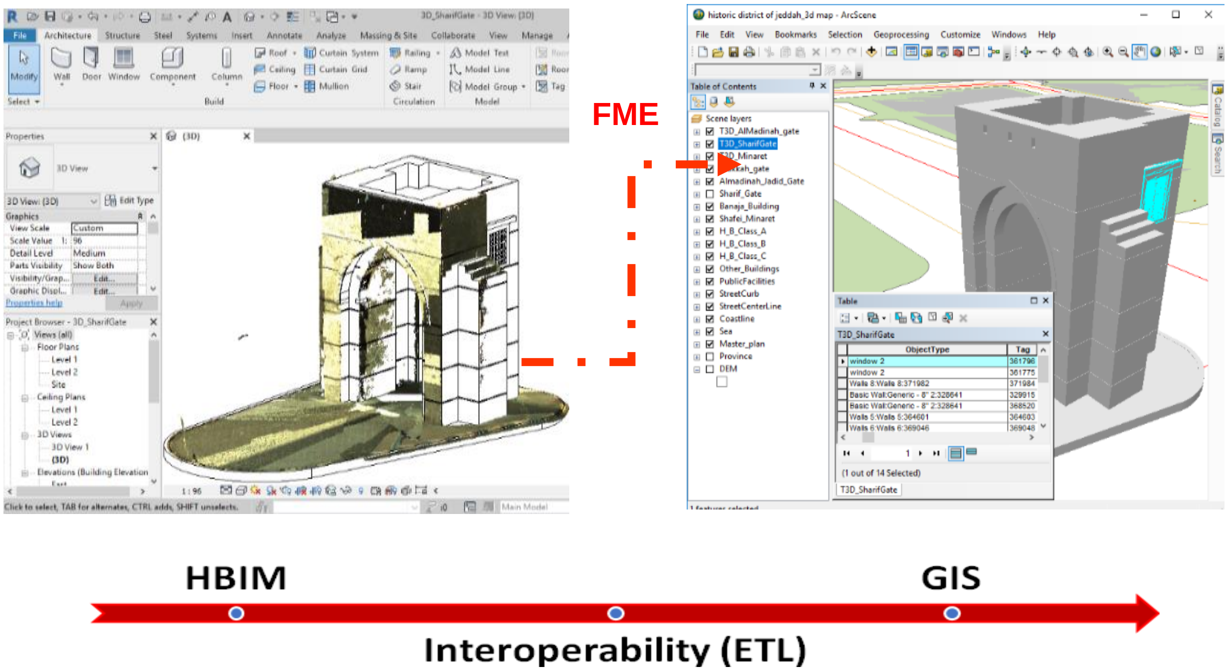

Figure 5.6: The output of HBIM Extracted from the Point Clouds Model into GIS-ArcScene

The GIS software used is Esri ArcGIS 10.6. Therefore, to import the data into ArcGIS, a workflow was developed, which allowed the integration of the 3D model of the Sharif Gate into ArcGIS and ArcScene through several complicated operations. Initially, the *.rvz file format was created by using the Revit FME exporter plug-in, which existed in Autodesk Revit (Figure 5.7).

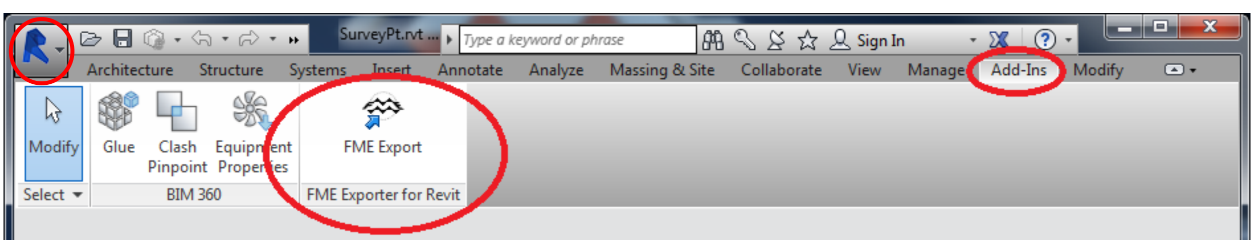

Figure 5.7: Creating *.rvz File by using Revit FME exporter plug-in, which existed in Autodesk Revit

This will make the matter possible to open this file (*.rvz) in the application FME Workbench, which will help in exporting the data from *.rvz into shapefile format (*.shp) to enable the opening of the required file (Sharif Gate) existing in the ArcScene (Figure 5.9).

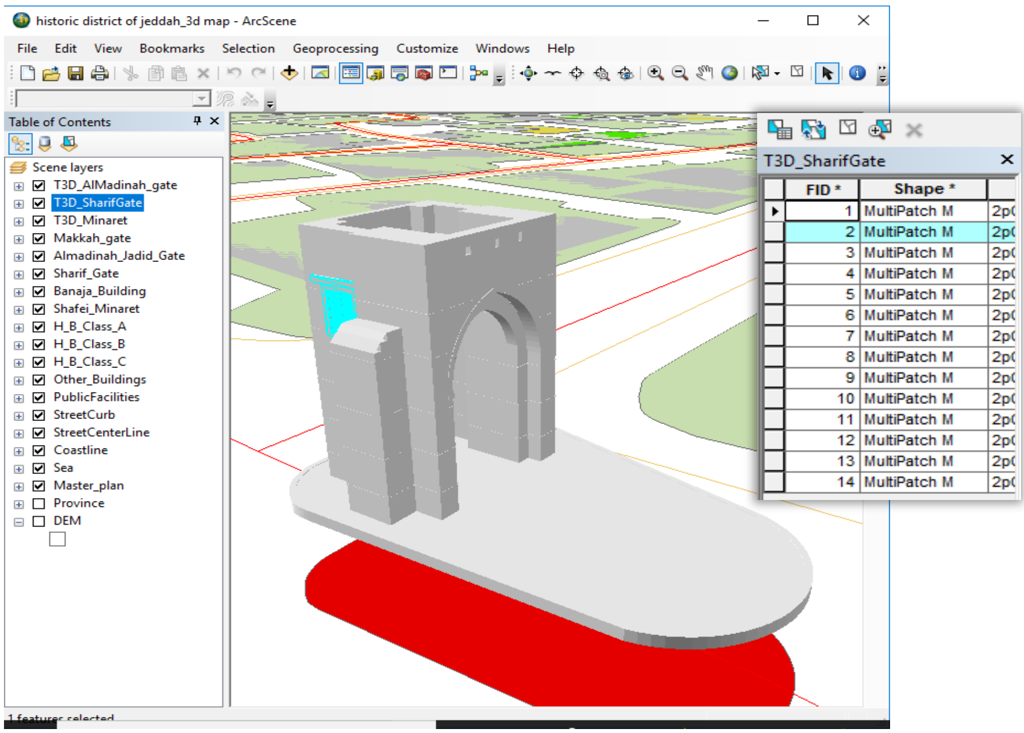

Figure 5.8: Opening and importing the file (*.rvz) into GIS-ArcScene

However, when the file extension was transferred from *.rvz to *.shp, in the application FME Workbench, to be opened with the program ArcScene, some errors appeared, which were not treated automatically in a correct shape, such as some materials' absence and errors in geometric of the 3D (Figure 5.8).

Later, the file *.rvz was verified with the "FME Workbench" application to ensure that (All) (Figure 5.9) of the structured information from Revit was exported, to be written and transferred or translated into significant formulas to be read and handled easily in GIS software.

This means that we did not conduct any amendment on the original data that existed from *.rvt. Therefore, in this step, we did not do a new cooperation, except assessing and testing the final output of such data to find out the degree of handling them. Consequently, we found them appropriate to meet the final objective of the study and have the required results.

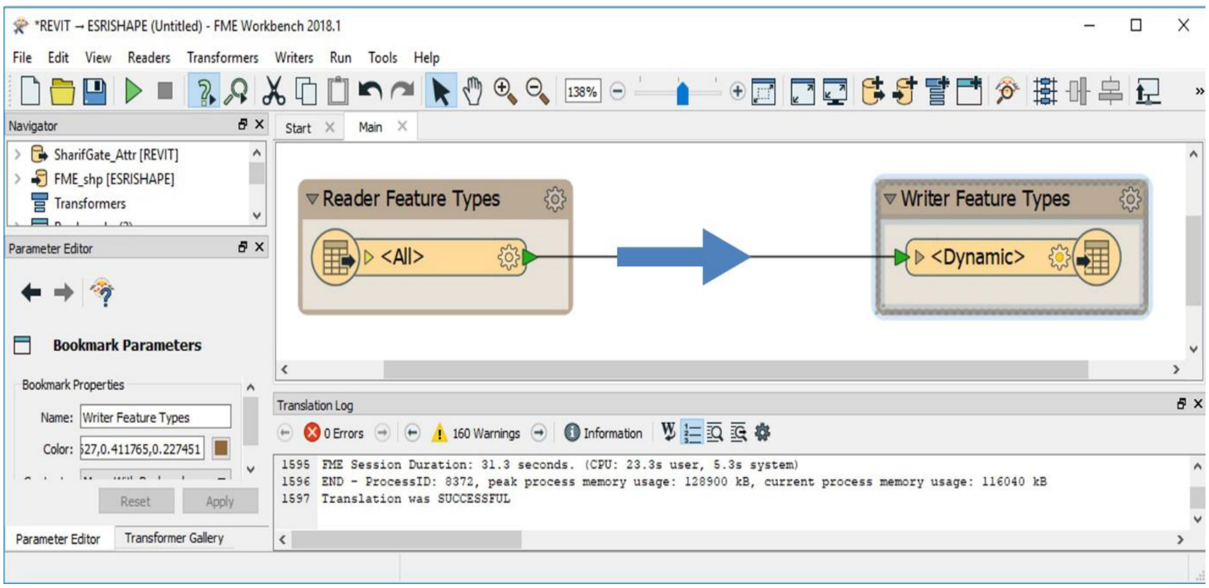

Figure 5.9: All the Structured Information from Revit was exported

After verifying the *.rvz file, the same was opened in the “FME Workspace” application and then converted into layers stored in multi-patch geometries in file geodatabase to maintain and manage the model and related information in ArcGIS/ArcScene. By importing file geodatabase in ArcScene, it was possible to navigate the 3D model while having the ability to execute complex queries, such as managing and maintaining the building’s life cycle while executing data editing and metadata enhancement, aiming to enrich the semantics of the model. Generally speaking, managing and maintaining the life cycle of the building should consider some queries, such as the process of design, construction, completion, commissioning, and as well as testing of any linked updating of the relevant documentation (As-built drawings, operation, and maintenance manuals) concerning all the work of reconstruction, restoration, rehabilitation, replacement or renewal of any element.

Theoretically, both geometric and semantic information should stay relatively consistent, when translated between HBIM and HGIS by ETL. However, this depends on the data knowledge of the operator on both BIM and GIS, basically for semantic information editing. The mapping process during the ETL can be flexible and customized between GIS and BIM platforms. In other words, ETL tools appeared convenient for bulk data conversion, similar to the one conducted in this investigation, which interpreted large-size data in a batch. Admittedly, sometimes errors are unavoidable during the model's mapping and the interpretation stage, as human processing involves and the irreconcilable differences between HBIM and GIS giving the justification to some manual editions were inevitable. Examples of some occurred errors are in the previous (Figure 5.8) and (Figure 5.10) shown hereinafter.

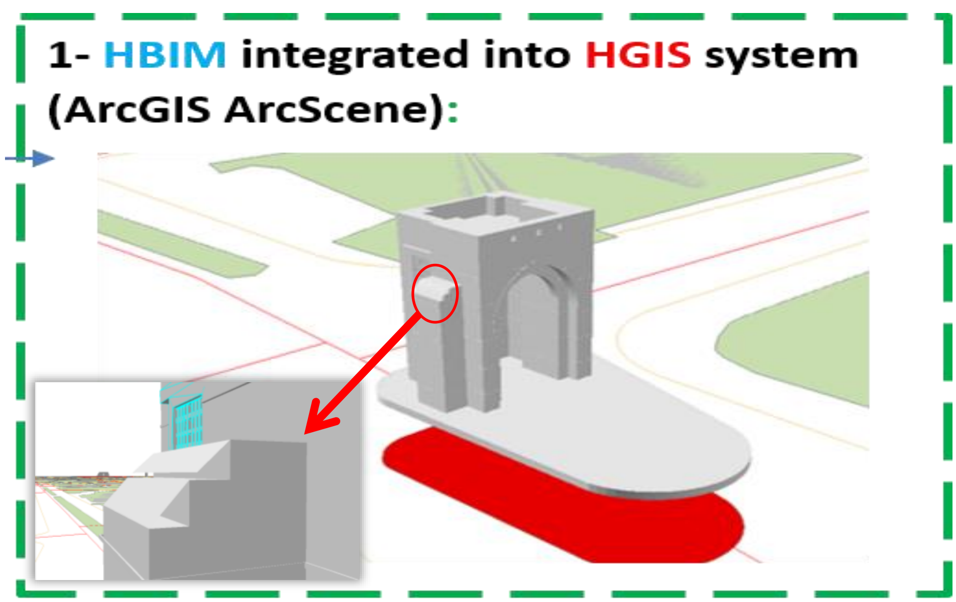

Figure 5.10: Examples of the errors and limitations in importing geometries and textures from BIM into GIS applications.

Despite the latest versions updated recently to ArcGIS, such as ArcGIS Pro, the same methodology results conducted by ArcGIS ArcScene can be obtained, if we analyze ArcGIS Pro, yet the appearance may be faster, respectively. However, we can check and correct errors with the usage of topology tools for clean geometry, e.g. for GIS errors. Topology can detect and correct errors in digitized data since it checks and validates the specified spatial relationship of overlapping and neighboring features (Martinez-Llarioa et al., 2017). It is critical to refer to the fact that, all the project data imported into geodatabase were subject to attributes as well as metadata editing, that in turn helped with the usability, retrieval, and management and fields like Shape, Shape_Length, Shape_Area, Name, Time_Constructed, Time_Reconstructed, whereas picture was changed, and updated using ArcCatalog application. These tasks provided users with BIM and GIS integration involves managing semantic information such as life cycle stages and historical references, as well as attribute data such as geometric accuracy and descriptive details, to ensure ease of use and relevance of the deliverables set with a clearer understanding of the dataset managed in ArcCatalog, as shown in (Figure 5.11).

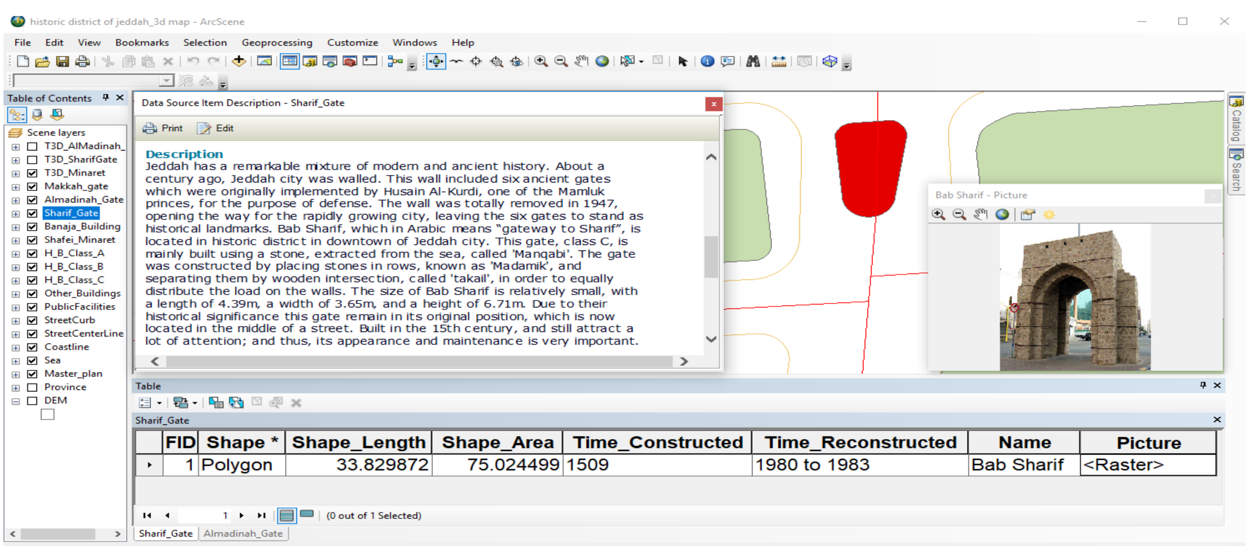

Figure 5.11: A Sample of Updating and Managing Attribute Data for Sharif Gate in the ArcScene environment

The system integration conceptual construction is sub-divided into the following steps:

Step 1. Indicate the input and output for HBIM (A.1 and A.2) and HGIS (B.1 and B.2), where;

A.1. Inputs for HBIM (BIM data source), consisting of georeferenced points cloud, photos/textures, and historic references (identified some elements in the attribute information/metadata/semantics).

A.2. Output (HBIM model) consisting of Georeferenced 3D HBIM, 3D architectural geometry (architectural information), textured and descriptive updated attribute data (rich semantic information). Autodesk Revit is used as a BIM platform (Figure 5.12).

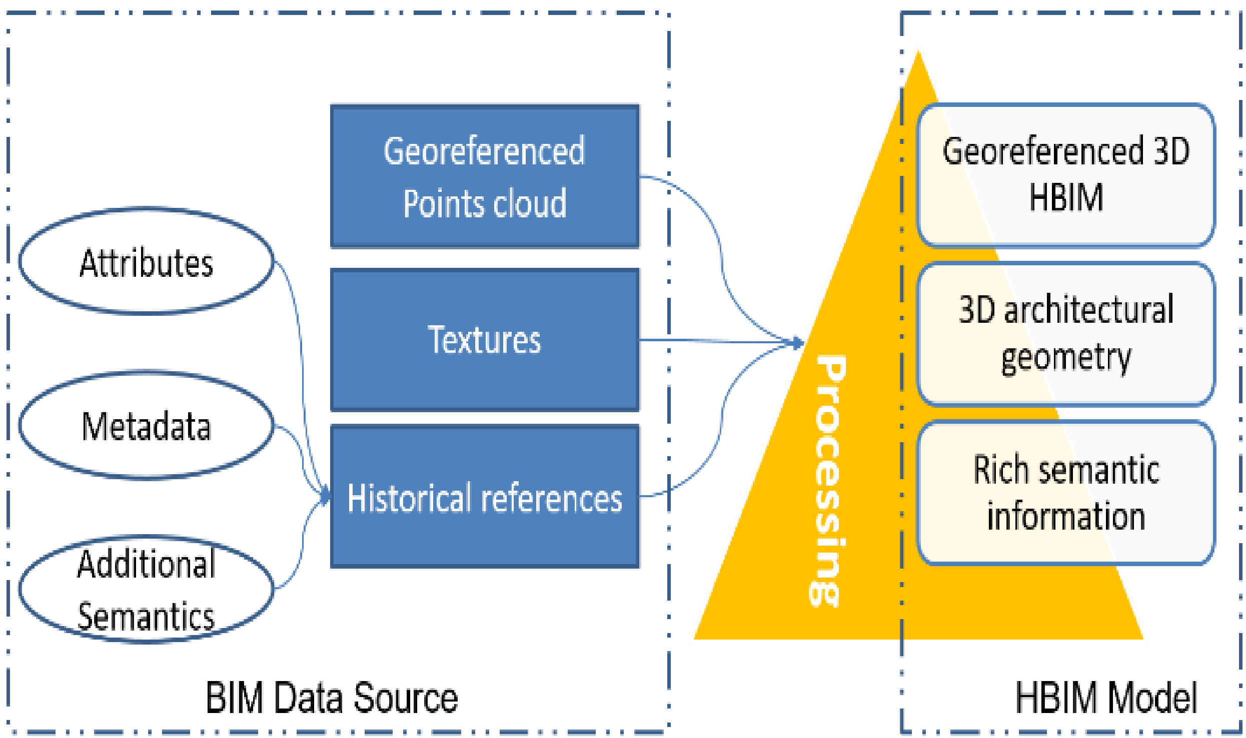

Figure 5.12: A) Input and output for the HBIM dataset

B.1. Inputs for HGIS consisting of Spatial references system, 2D CAD drawing (DWG), Original geospatial vector layers, and Historic references (Attributes, Metadata, Semantic and Classification information).

B.2. Output consisting of Georeferenced 2D HGIS, 2D geospatial information (non-architectural information: Vector, raster attribute), Updated geospatial vector layers, descriptive/updated metadata, and attribute data (Rich semantic information). ArcGIS (Map/Scene) is used as a GIS platform (Figure 5.13).

The 3D HGIS-HBIM data model based on semantic integration uses 3D spatial information, attribute data, and metadata data alongside historic building information modeling and GIS datasets. The development of the model will be implemented based on the following workflow;

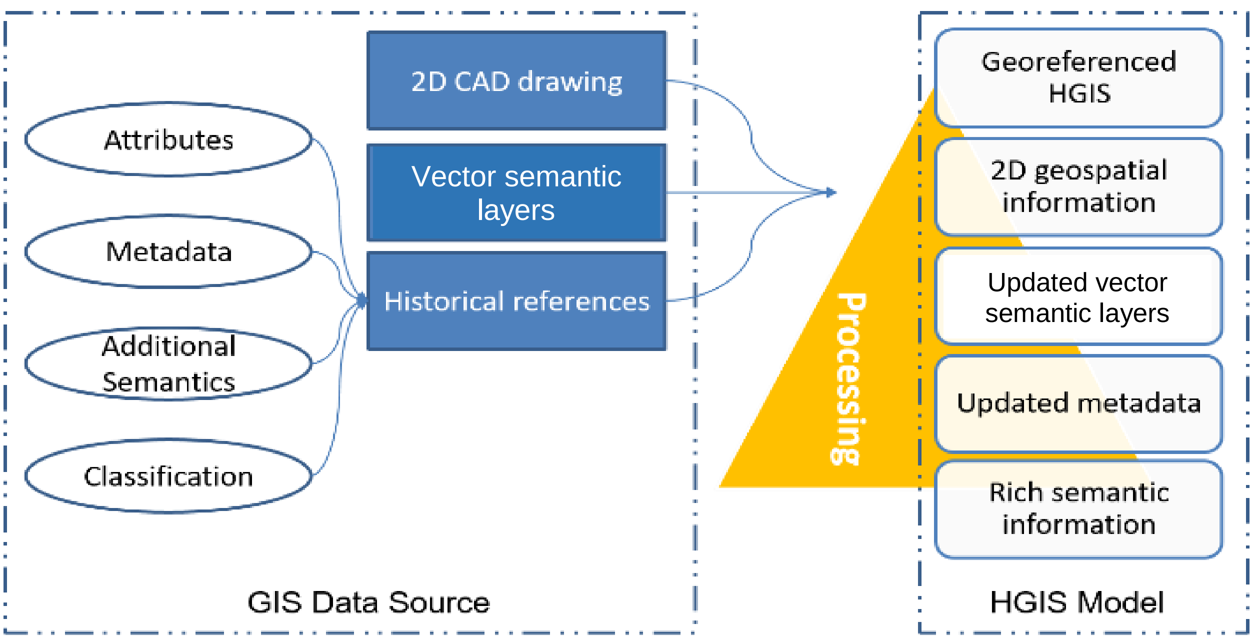

Figure 5.13: B) Input and Output for the HGIS Dataset

a) Source GIS datasets are collected and used as geospatial vector layers (shapefile format), then imported into a structured spatial geodatabase. After multiple tests in selecting a suitable format for the relevant dataset, the Esri geodatabase format was selected given its access performance and faster data querying (Cheng, Q., 2016). The BIM model from the Revit project is used after conversion to an IFC (industry foundation classes) and then imported into a file geodatabase features classes with Multi patch geometries.

b) Both features from GIS and BIM models are stored and maintained in a unified spatial database.

c) An editing workflow using ArcMap and ArcCatalog to enhance the properties, metadata, and logical data model of all layers in the spatial geodatabase.

d) A scene layer created from datasets is processed using GIS applications (ArcScene, and InfraWorks 360).

e) Publishing web services and web-scene on Autodesk cloud platform, then consuming these services into a targeted user's applications.

Step 2. HBIM & HGIS model Outputs are integrated into a GIS platform

To handle the 2.5D digital terrain model, 3D block model extruded from polygons, and multipath 3D model generated from other sources, the generated HBIM and HGIS models are exported into the 3D GIS ESRI ArcScene software. The workflows are based on the interoperability between the ESRI ArcGIS software and Autodesk Revit. The 3D objects are constructed based on the 2D data which define the reference system for the 3D model. Exporting features to ArcGIS and visualizing them, the ArcGIS Toolsets and scripts can be used to correct and project data.

The ArcScene application in ArcGIS 3D Analyst Extension allows the users to manage and visualize 3D geographic data, therefore making it an appropriate tool to edit attributes and multi-patch geometries information as well as the metadata of the 3D model. The final model is stored in a file geodatabase created by the user during the export process, meaning that a 3D feature is represented by a single record in the file geodatabase. The following cases were observed:

a) **The texture and geometry** of 3D HBIM have not transformed adequately (even when the interoperability extension "FME" is used).

b) **Attribute table:** All the HGIS data were transformed well, however, the 3D descriptive elements of HBIM are different from the original attribute data table imported from the Revit platform. For example, after extracting the 3D model from the point clouds using the Autodesk Rivet platform, the 3D model was then imported to ArcScene using the interoperability tool "FME". The data integration we used in this research work is based on designed workflows using FME-embedded data transformation algorithms to extract semantics (attributes, geometries, and metadata) from both HBIM and HGIS. Due to these processes, the textural and geometrical data were not transformed optimally, as shown in (Figures 5.14 and 5.15), respectively.

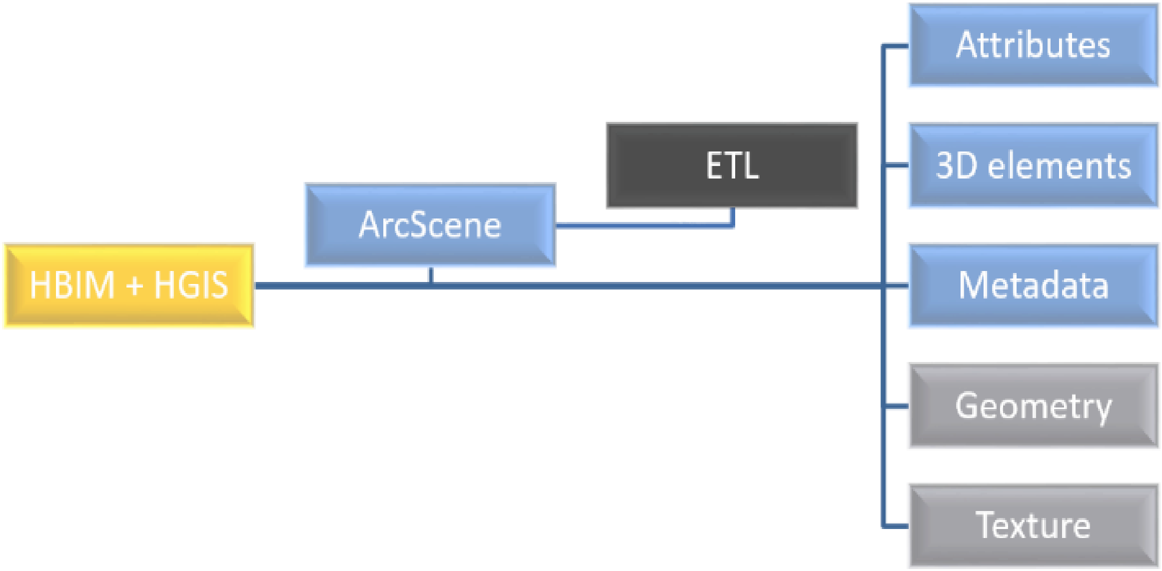

Figure 5.14: Outcome of integrating HBIM / HGIS using GIS Application (ArcScene)

To shed more light on the previous (Figure 5.14), the grey color represents the fact that for HBIM-HGIS integration, (first approach); the textural and geometrical data were not transformed optimally. However, in the second approach; this grey color illustrates that most of the HGIS data were transformed well. However, the 3D HBIM was imported as one block, and thus its elements cannot be identified separately in the attribute as the original one, which was created in the BIM platform (Figure 5.17).

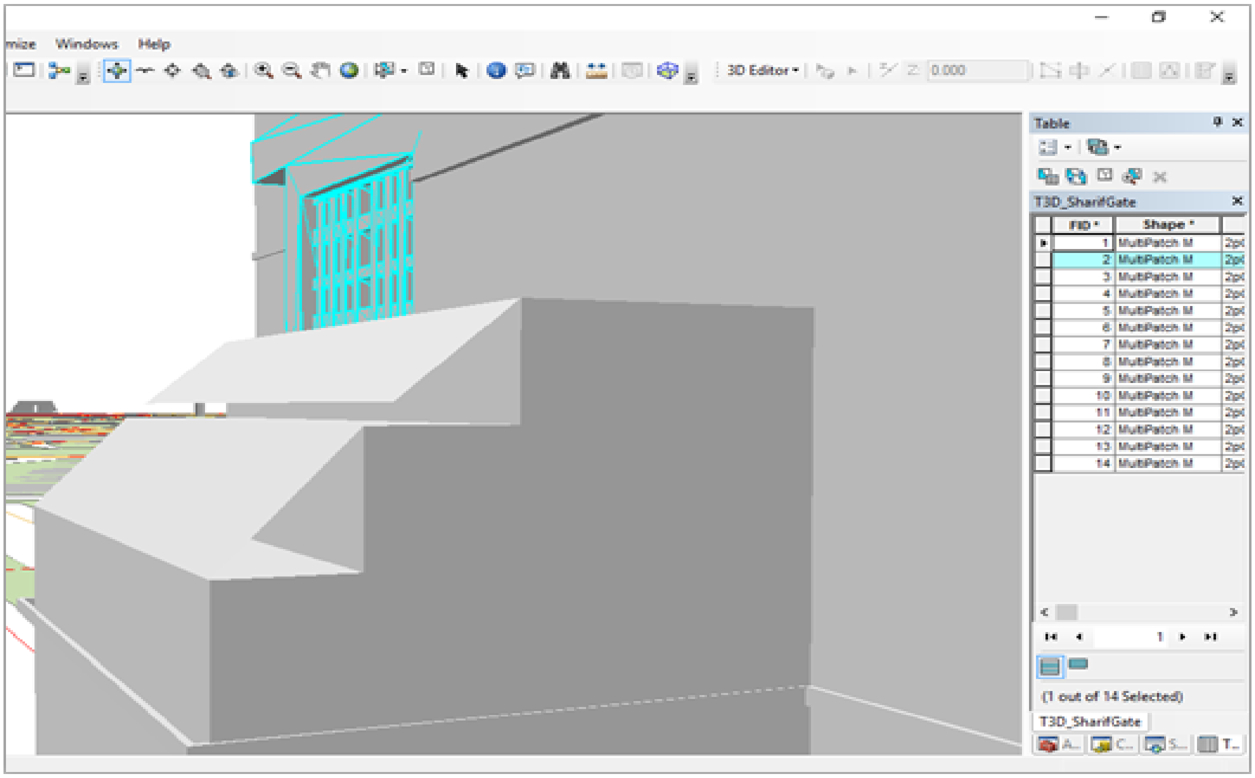

Figure 5.15: 3D HBIM Model Integrated into GIS System (ArcScene)

Being settled with completing the first stage of the research design, that is the HBIM transfer into (H)GIS environment, the following step will focus on the necessity to explain the second process of integrating both HBIM and HGIS into a separate platform (Autodesk InfraWorks 360), to mitigate the significant limitations in texture and geometry, along with providing optimal results.

5.3.1.2 Required Tasks and Tools for the HBIM-HGIS Integration into HGIS Platform

BIM/GIS integration approaches have the resulting model, hosted on a GIS platform (Zhang, et al., 2009). As for our study here, the BIM/GIS will be tested, in which the HBIM data will be transformed to GIS (Arc Scene) utilizing Autodesk Revit through an interoperability extension (FME). In 2013, George Washington's Mount Vernon home was laser-scanned for historic conservation to create high-quality HBIM using the BIM platform (Revit). Interoperability extension (FME) is used to convert BIM to GIS by exporting georeferenced Revit data with FME Revit Exporter and then importing it into ArcGIS using another separate data interoperability extension (FME Workbench). Attributes needed to be reconnected and Web Scene is used for delivering an easy sharing of the rich detail extracted from BIM with the spatial context of GIS. However, this model cannot be shared easily with the public and provides an easy interactive user experience and Immersive visualization. Furthermore, complex processes need to be done to convert data into a unified building model in one application. This process is not as simple as it appears here, because each BIM file involves a lot of data, and working on it concerning the ArcGIS becomes a very computationally complex and tedious task. Later, we will get into some details on how the FME extension is used in doing this.

5.3.2 HBIM-HGIS Integration into a Separate Platform (Autodesk InfraWorks 360)

The previous parts discussed the workflow of integrating HBIM and HGIS into the GIS domain, which commenced with data collection. It included three sources of data, passing by data processing, and finally data integration to be published. As a result, all information was collected in one place that was accessible to users at any time. This will ensure transparency and the ability to resolve design issues that will be revealed and addressed at an early stage to leave room for proposal reiterations. Throughout the process, it may be possible to create different proposals within one model. Besides the integration of HBIM/HGIS into GIS, the integration of HBIM and HGIS into a separate system has also been implemented, as shown in (Figure 5.16).

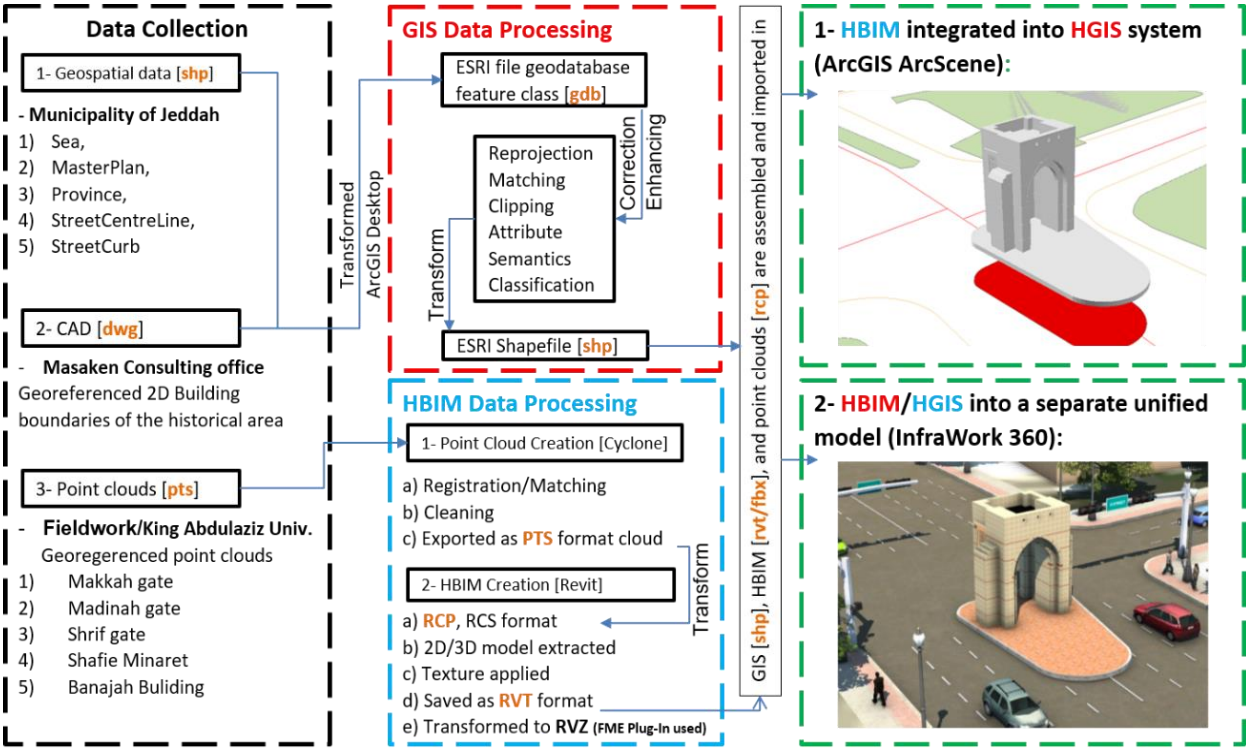

Figure 5.16: Integration of HBIM/HGIS into a Separate Unified Platform

The generated HBIM and HGIS models were then exported into InfraWorks for user manipulation and interaction with the study scene. In this phase, a new integration workflow using AutoDesk InfraWorks was developed to import and process data.

Autodesk InfraWorks 360 allows developers to analyze model designs with relevant neighboring information provided by the GIS platform, such as terrain features, transportation networks, and in many cases other BIM models as well. This allows for the BIM model to preserve high visual quality with a high level of detail by using the information from the model itself and the geographic features around the targeted model. In this case, the Terrain model generated from point clouds and aerial imagery is matched easily. Besides, the GIS data are easily imported and updated as:

a) **The texture and geometry** of the 3D HBIM were directly transformed from Revit, and a reference system was created without the need for interoperability extension.

b) Attribute table: Most of the HGIS data were transformed well; however, the 3D HBIM was imported as one block, and thus, its elements cannot be identified separately in the attribute as the original one that was created in the BIM platform (Figure 5.17).

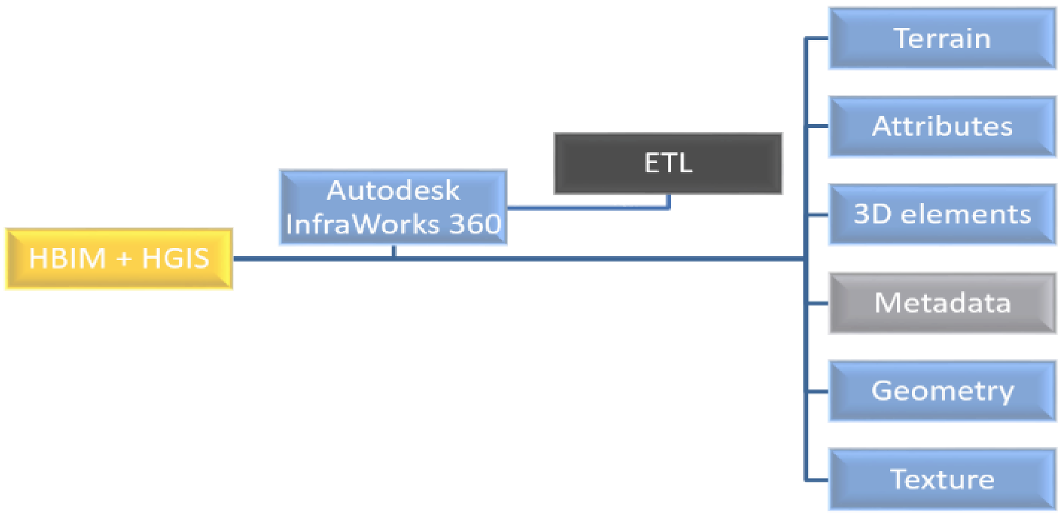

Figure 5.17: The outcome of integrating HBIM with HGIS using InfraWorks 360

Both the web service and web scene created from the previous step will be published and queried together into a single web platform hosted on Autodesk InfraWorks 360 cloud-based service, which allows advanced geoprocessing analysis. Finally, these web services will be consumed into immersive user experience web applications enhanced with spatial data querying capabilities.

5.3.2.1 Digital Representation of a Historic Monument

To restore the historic monument, by creating compelling 3D models of real places and applying enhancements for realistic and interactive results Autodesk, InfraWorks 360 was used.

To understand InfraWorks 360, the user needs to be aware of the GIS data and how to use it to create a reference model (Autodesk, 2012). InfraWorks can process a wide range of different types of data formats into a single model. It includes common file extensions that can be run when combined with web or GIS data. If there is no determined GIS data, the user can start using National Map Viewer and find data anywhere in the USA. Despite not being the best data viewing tool available it is a good starting point. If the site is outside of the USA, the user can use any search engine to look for GIS data (Chappel, 2015).

The advantage of using InfraWorks is its simple and user-friendly interface. The user might simply select the desired area, and then use available tools to build a 3D model. With this platform, the user can create a 360-degree model and populate it freely with available GIS data. Design features, such as roads, buildings, vegetation, and city accessories, are easy to recreate (Chappel, 2015). According to Autodesk, the user needs to start with the terrain to create a base model that establishes the model elevation and other data attached to it (Autodesk, 2012). Then, a ground image, usually an aerial image of the model, will be added to this terrain to make a realistic model texture. The next step is about adding transport paths to the model that consists of building roads, railways, bike paths, or any other location features. After this, other features such as water, buildings, furniture, and other data can be added to create a realistic model. Therefore, Autodesk InfraWorks 360 was used instead of ArcScene to solve the limitations in texture and geometry and provide optimal results, since the former supports detailed models in structures. It is considered a GIS application, which is free, capable of managing a lot of data, and compatible with BIM and GIS data. Consequently, the model builder for extracting elements of the historic area will be the critical step in this research while the details will be discussed later.

5.3.2.2 Model Builder for Extracting Elements of the Historic Area

Model Builder in ArcGIS adds several capabilities, including the process of creating models by connecting data and tools, while allowing the users to visualize the workflow sequence as an easy-to-understand diagram. Therefore, Model Builder of ArcGIS is used as a first step that is essentially an aggregating portion of the software that combines base data for roads, buildings, imagery, and elevation. Most of these data come from:

a) Roads (openStreetMap); b) Buildings (openStreetMap); c) Imagery (Bing Map); and

d) Elevation (USGS National DEM). The classified buildings, supported by using Matthew's 1979 classification rules, are imported into InfraWorks 360 as geospatial vector layers (Shapefiles) and/or dwg files to update the data sets (Figure 5.18).

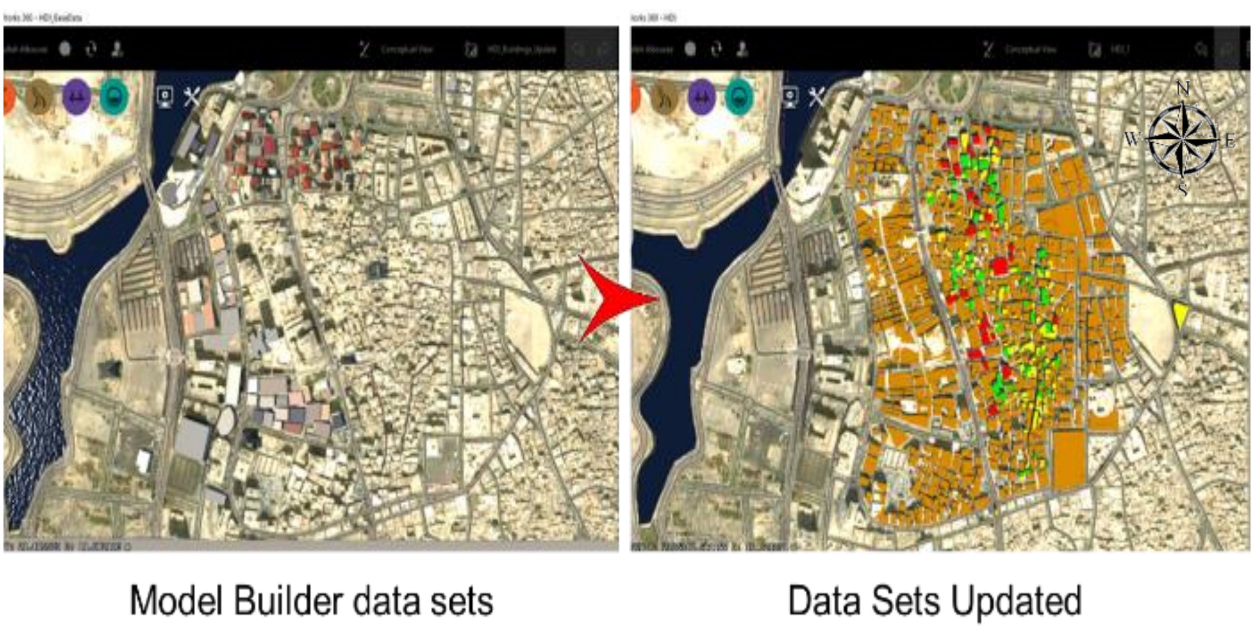

Figure 5.18: Classified Buildings Data Sets are Updated

5.3.2.3 Terrain Model Extracted from Point Clouds

To generate an accurate DEM for the historic area, point clouds are used to extract the terrain model (Figure 5.19). The terrain model was generated from point clouds with the Autodesk InfraWorks 360.

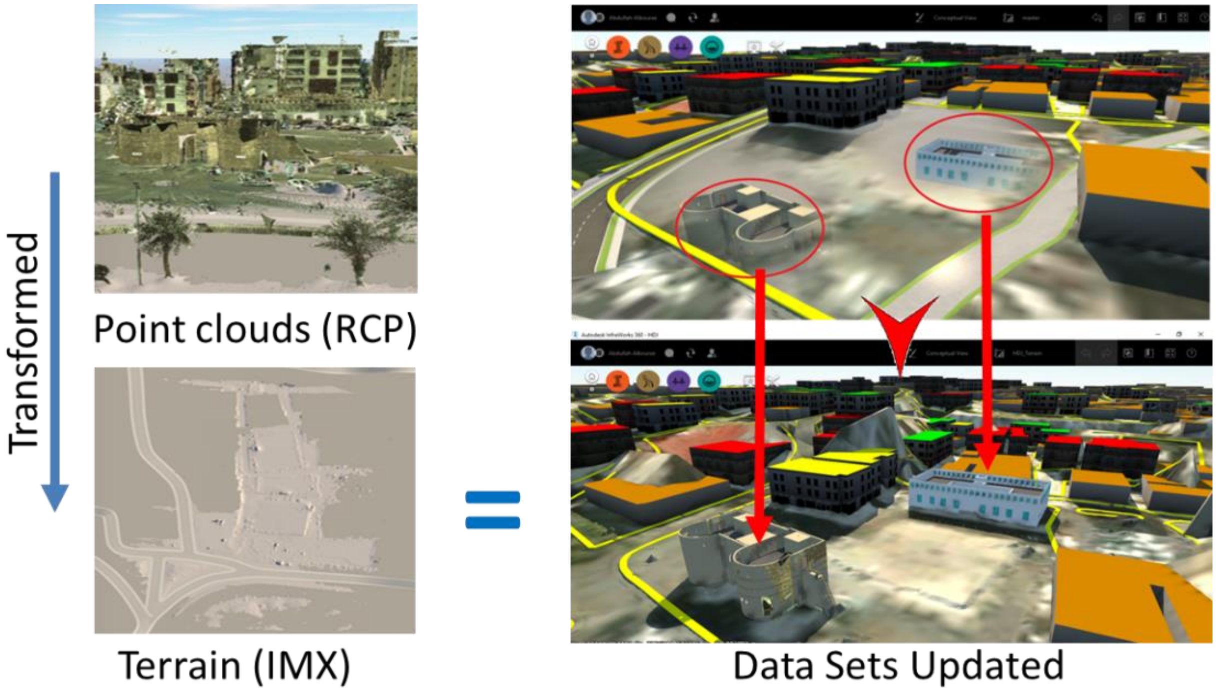

Figure 5.19: Update the Digital Terrain Model based on the Point Clouds

5.3.2.4 3D Models Updated

Autodesk InfraWorks 360 enables the location of 3D models directly from Revit with its texture and reference system accurately, which is used for updating the data sets as illustrated in (Figure 5.20).

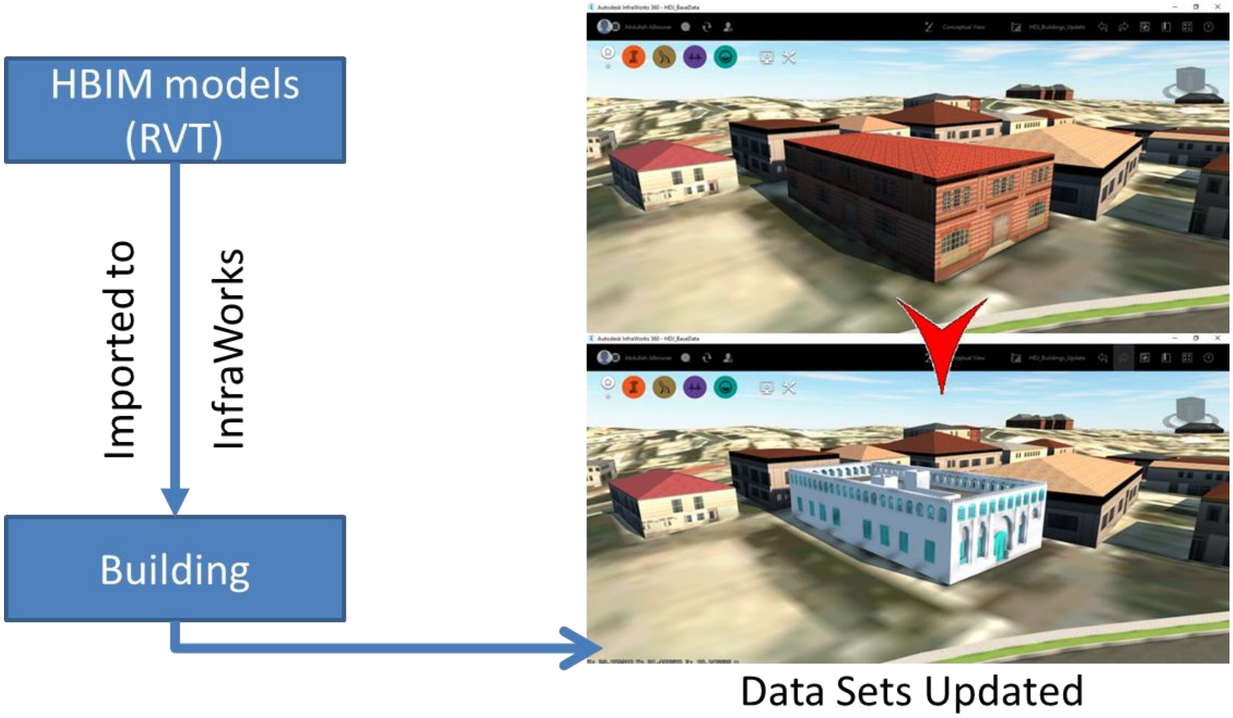

Figure 5.20: Update Buildings using Georeferenced HBIM Data Models

5.3.2.5 Datasets of the GIS Data Layers Are Updated

Autodesk InfraWorks 360 also assists in integrating all enhanced/corrected GIS data layers as geospatial vector layers (Shapefiles), such as StreetCenterLine, and StreetCurb. An example of this integration; the 3D model of Sharif Gate looked like it was in the wrong place, however after the GIS data was imported and updated; the 3D model appeared in its correct location, in the middle of the street, as seen in (Figure 5.21).

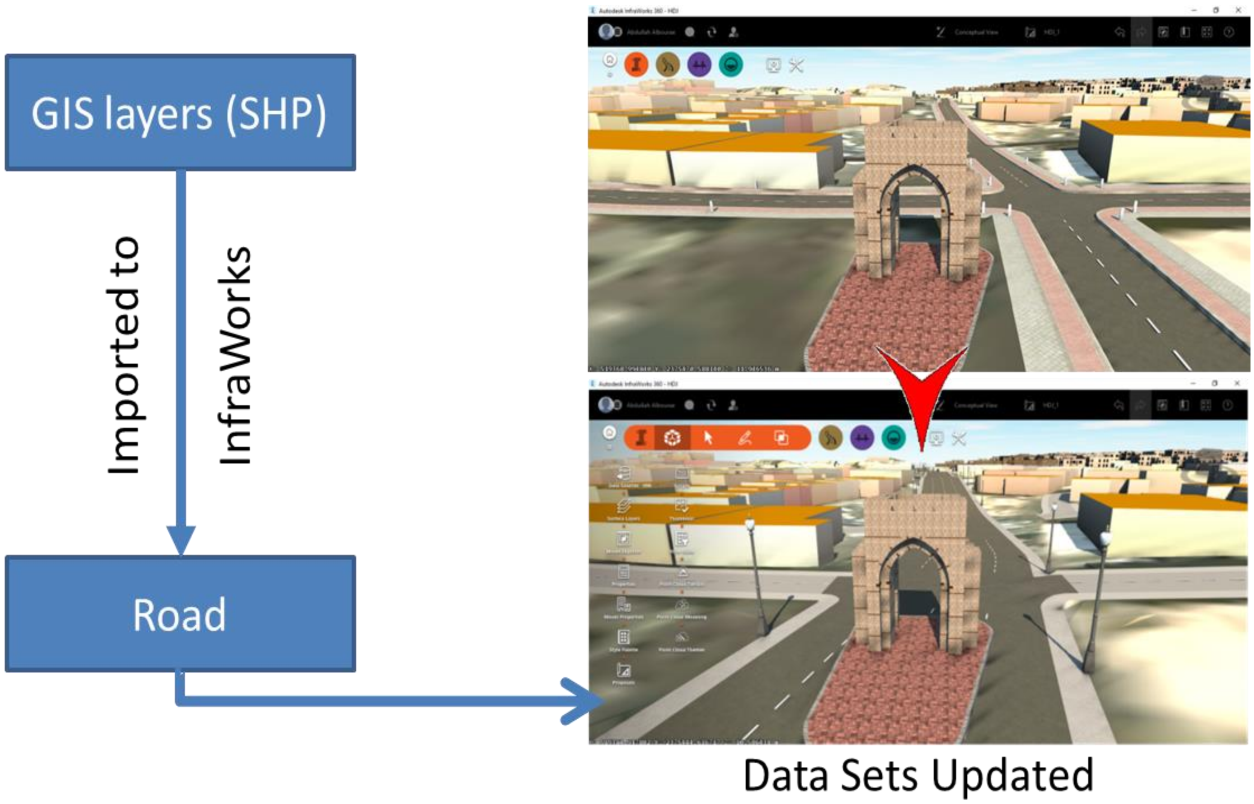

Figure 5.21: Datasets of the GIS Layers are Updated

This section discussed constructing the physical HBIM and HGIS models. The conceptual model refers to the high-level components from BIM and GIS (not specific attributes) used to create the model. The HBIM attributes are represented in the name of the elements of 3D models and their geometries modeled from point clouds (Figure 5.22), which are generated by us and supported by historical references. On the other hand, the HGIS attributes represented in more information, such as Field ID, Shape, Shape_length, Shape_area, Name, Time_reconstructed, Time_constructed, and picture (attachment) generated by us as well, as metadata and classification of historic buildings for exploring the selected and enhanced 2D geospatial data which supported by point clouds, CAD data, geospatial vector layers, and historic references.

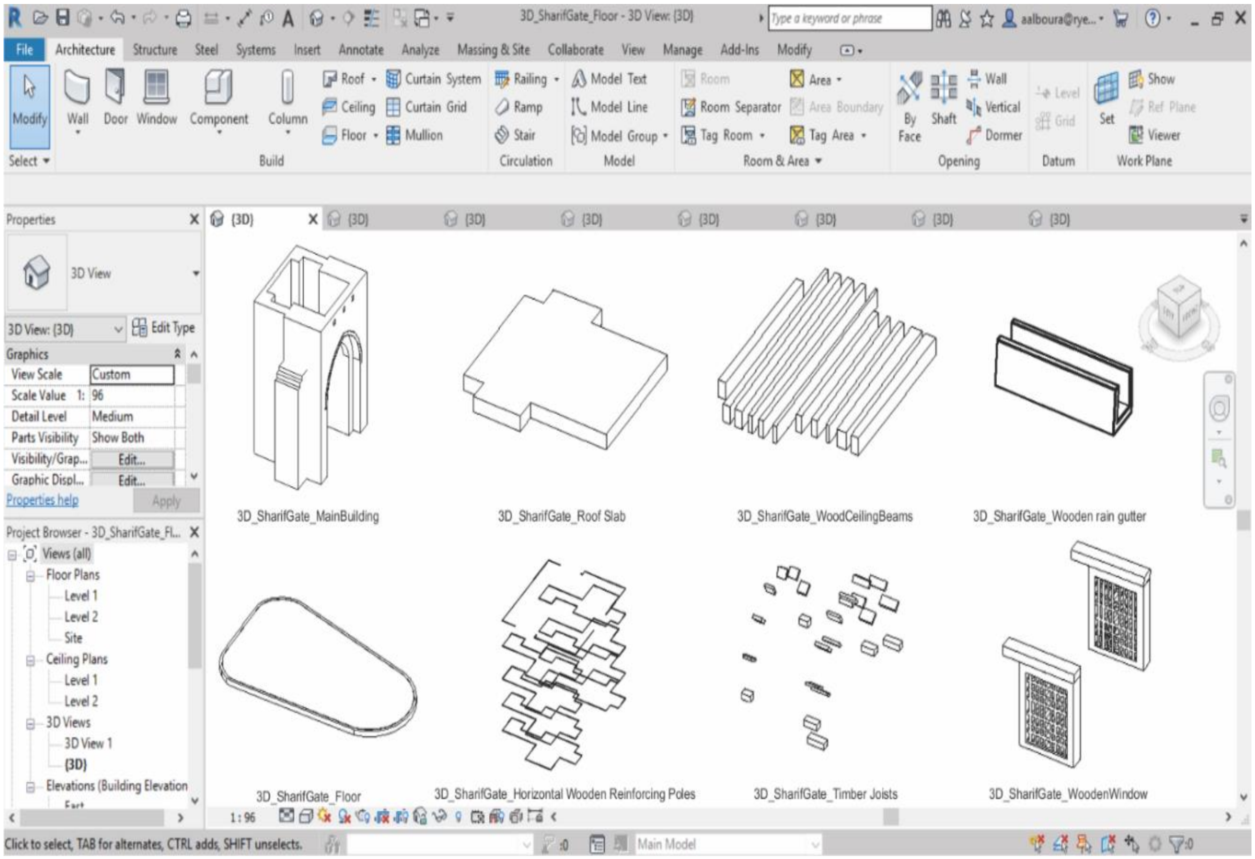

Figure 5.22: Names and Geometries of HBIM Modeled From Point Clouds

5.4 Differences and Challenges related to HBIM-HGIS Integration

Table 5.1 highlights the hurdles encountered when merging HBIM (detailed building data) and HGIS (broad historical context) after their initial creation. The main difficulties stem from inherent differences in data structures, scale, and how information is categorized (semantics). Achieving a unified model hinges on overcoming these challenges by harmonizing these aspects, ensuring consistent geometric representation, and adapting to the varying scales of the data. The most significant hurdle lies in reconciling these fundamental differences. To achieve seamless integration, careful planning, robust data management strategies, and appropriate software tools are essential.

Table 5.1: Differences and Challenges of HBIM-HGIS Integration

Category	HBIM Focus	HGIS Focus	Challenges
Modeling Language	Historic building documentation & preservation	Integrating historical data with geographic information	Harmonizing semantic definitions & attributes for interoperability
Geometric Representation	Detailed representation of historic buildings	Spatial representation of historical information (events, boundaries)	Integrating detailed HBIM geometry with HGIS spatial representation
Semantic Information	Historical significance, cultural value, architectural details	Historical events, people, cultural aspects	Addressing disparities in semantic information and harmonizing conflicting semantics
Coordinate System	Local system specific to building/site	Global system (latitude/longitude)	Aligning local HBIM systems with global HGIS systems
Spatial Scale	Specific buildings/sites (detailed representation)	Larger areas (cities/regions)	Adapting to different scales for data consistency and reliability

5.5 Commercial Off-The-Shelf (COTS) Software Tools

The goal of this project is to integrate HBIM/HGIS technologies with immersive and interactive tools to provide a workable solution that will aid in the protection of Jeddah's historic site. The primary contribution of the dissertation is the design and development of a workflow process that makes use of commercially available software (COTS) to show that the project is feasible and can be easily implemented in different settings. The study aims to fill in the gaps in the existing literature, provide mitigation strategies, and present a methodological framework for combining BIM/GIS and heterogeneous information into a single interactive platform.

Through portable and augmented reality devices, the project intends to improve users' spatial experience, boost context-awareness, and improve accessibility to digital data. It also explores additional levels and model kinds to fulfill diverse application demands and needs.

For the integration of HBIM and HGIS, the following tasks and tools are required, as shown in table 5.2.

Table 5.2: Necessary tools and tasks for enabling HBIM/HGIS integration

Items	Tasks	Tools
1	Correct and project data.	ArcGIS
2	Convert BIM to GIS by exporting georeferenced Revit data with FME Revit Exporter and then importing it into ArcGIS using another separate data interoperability extension (FME Workbench).	Feature Manipulation Engine (FME)
3	Allow developers to analyze model designs with relevant neighboring information provided by the GIS platform.	InfraWorks

Based on the above table 5.2, COTS application software was used, such as ArcGIS, Feature Manipulation Engine (FME), and InfraWorks. We will explain each of them in brief.

5.5.1 Use of ArcGIS

ArcGIS is a mapping and spatial analysis software. It operates as client, server, and online geographic information system. Given that and according to the illustration of Harder (2015), the rapid evaluation of the unit division and the spatial overlay analysis function of the ArcGIS can significantly avoid time-consuming statistics work during the evaluation of geo-hazards susceptibility, and meanwhile, the evaluating results are roughly accurate.

5.5.2 Use of the Feature Manipulation Engine (FME)

FME can be considered as the former tool that has been designed, to be such a spatial ETL application, with a focus on translating geographical data. It is apparent that, recently, the capabilities of FME's ETL can cover various data; spatial or non-spatial. The limitations are that neither all conversions nor compatibilities will have all features available. With FME, the users can work with BIM complicated data and filter information, according to their requirements.

The pre-built systems and technologies, including ArcGIS, Feature Manipulation Engine (FME), and InfraWorks, were selected due to their particular aptitude for managing spatial translations, 3D modelling, and geographical data. The rationale behind the choice of these software tools is their capacity to effectively handle and modify information for the conservation of cultural assets.

On the other hand, there might be restrictions on transformations, like partial conversions or problems with specific features not working properly. Even though these solutions have many useful features, managing different kinds of data or guaranteeing seamless integration may not be possible.

Examining other systems that are compatible and looking into other tools that provide better compatibility, more extensive feature support, and better data processing capabilities may improve the heritage conservation strategy as a whole. A more reliable and effective workflow could result from the introduction of new technologies that solve the shortcomings of the current systems, improving data integration, analysis, and visualization in the context of heritage conservation.

Based on the particular activities and requirements involved in the integration process, the choice of Commercial Off-The-Shelf (COTS) software tools for integrating Historic Geographic Information System (HGIS) and Historic Building Information Modelling (HBIM) is justified. The seamless integration of HBIM and HGIS data requires the usage of tools like ArcGIS, Feature Manipulation Engine (FME), and InfraWorks.

The technology chosen for spatial Extract, Transform, Load (ETL) applications that concentrate on converting geographical data is called Feature Manipulation Engine (FME). When working with complex BIM data and filtering information based on specific criteria, FME is a valuable tool due to its adaptability in processing different types of data, both spatial and non-spatial.

A program licensed by Autodesk called InfraWorks is used to create 3D models of actual locations and enhance them to produce realistic and interactive outcomes. Its capabilities and user-friendly interface make it ideal for efficiently integrating GIS data and viewing historic monuments.

All things considered, the rationale behind the choice of these commercial off-the-shelf software tools is that their particular features correspond to the tasks necessary to combine HBIM and HGIS data in a way that makes it possible to analyze, translate, and visualize historical building information in a geospatial context with efficiency.

On the other hand, taking into account the difficulties encountered in the preservation and documentation of cultural heritage places might help to solve the constraints on the modifications associated to tools or models. The lack of georeferenced, high spatial resolution documentation, outdated documentation techniques that don't meet modernization standards, and a dearth of applications to meet the vast demands of recording, documentation, conservation, and tourism are some of these challenges. Complicating matters further, the lack of digital materials required for conservation initiatives makes the preservation of important historic places more difficult. These drawbacks emphasize how crucial it is to choose suitable off-the-shelf solutions and equipment to get beyond these obstacles and improve the preservation and sustainability of cultural heritage sites like the Jeddah Historic Site.

The dissertation also addresses how to improve historic site conservation by integrating different technologies including HGIS, HBIM, AR, VR, and interactive displays. It also highlights how crucial it is to use immersive and interactive technologies in order to digitally recreate and model ancient treasures for future generations. Additionally, it has been mentioned that Autodesk cloud services can be used for design, collaboration, and information sharing at every stage of the product life cycle.

The dissertation recommends using City Geographic Markup Language (CityGML) as a rich multilevel dataset to express 3D-GIS and IFC BIM modelling in the integrated HBIM-HGIS model, in relation to other compatible systems. The conservation of historic heritage sites may benefit from this integration of the CityGML and IFC data models.

5.5.3 Use of InfraWorks

The Autodesk-licensed software InfraWorks enables the process of creating a 3D model of real places and later proposes enhancements for realistic and interactive results. To understand InfraWorks, the user needs to understand what GIS data is.

Quite simply stated, the advantages of using InfraWorks centered on its simple interface. The user might simply, select the desired area and then use the available tools to build the 3D model. With this software, the user can create a 360° model and populate it with freely available GIS data, create the most design features like roads, buildings, and coverage, and add some details to them, such as vegetation, and city accessories (Chappel, 2015).

5.6 Summary

In this chapter, we presented the methodological approaches to achieve HBIM and HGIS integration focusing on semantics, attributes, and geometries. We focused on two main approaches; HBIM-HGIS integration into the HGIS platform and HBIM-HGIS integration into a separate platform. Combining the advantages of both domains can provide richer models and complete semantics, despite many challenges in data translation and corrective measures used for troubleshooting errors.

The author's methodology would probably be significantly impacted by the advent of new tools and technology. These technologies might offer more sophisticated features for data processing, visualization, and display. For instance, the integrated model's usability and accessibility could be enhanced by the incorporation of 3D viewers and mechanisms for unified geographical inquiries. The author also discusses evaluating workflows and tools for potential future development, suggesting a process of ongoing improvement when using technology for cultural protection.

The process consisted of several stages, from collecting and processing GIS datasets and using laser data to identify different components of an HBIM-HGIS combined system. One of the most critical results was a full 3D model that included the original geometrics, semantics, and edited metadata. The HBIM models can be published with Web Map services, which can be queried together into a single web platform hosted on Autodesk 360 Online.

Chapter 6 : Visualization - Interactive User Environment

6.1 Introduction

In this chapter, we discuss the concept and implementation of an interactive user environment, the architecture and modeling, and the main requirements, according to the Conceptualization of the User Experience. Moreover, we explain the Graphical User Interface (GUI); passive display, and interactive display. Finally, the process of visualization, interaction, and immersive environments explanation takes its place. This is, while referring to tools and approaches; Web Browser, Augmented and Mixed Reality (AR/MR), and Game Engine, respectively.

6.2 Scope of the Study

The main concern of this part is answering the following crucial questions:

a) What are the requirements of the users (The Architecture, Engineering, Construction, and Owner/Operator industry (AECO)? How can interaction with historic models be designed to satisfy the immersive-user experiences' needs?

b) How can the outcome of HGIS and HIBM integration assist the interactive user experience creation?

c) Which components and content of the virtual HBIM/HGIS model would the user interact with on the website, to augment reality and game engine systems?

6.2.1 Conceptualization of the User Experience

Generally speaking, the term “user experience” stands for a feeling the user experienced, in particular when using an application or a product. It is a so wide term, that covers anything from the way by which the user navigates the specified product or an application, how easy it is to use, and how relevant the specified contents’ display. To meet the expected user experience, for example in the historic heritage conservation process, the process of designing should be useful, the contents be original and fulfill their needs, and the design should be easy to use. Other elements to make the matter easy to meet the expected user experience are to make the design desirable and findable for the user, either onsite or offsite (Poux et al., 2020).

6.2.2 Requirements According to the Conceptualization of the User Experience

To deliver the user experiences, the Architecture, Engineering, Construction, and Owner/Operator industry (AECO) collection needs to be captured. Thus it is imported from the previous chapter of integrating (HBIM) and (HGIS) integrated for visualization of historic monuments, importing the texture features, the architectural components (doors and windows), structural elements (wooden beams, walls, and ceilings), and the GIS elements, such as roads, aerial photographs, terrain, building roads, railways, building boundaries and sidewalks, or any other location feature. All these were imported well without major changes or corrections. The main objective is to establish a prototype of a virtual scene in a specified game engine application by creating;

a) A passive display for VR user experience and;

b) An interactive display through implementing this virtual experience on the website, and game engine and utilizing AR systems. This will create the AR user experience.

The passive style facilitates the users' access to the models, via URL links or even and QR-code reader application at one location in 360°, while the interactive style facilitates the users' process of creating their experiences through either a web browser, AR (Consuming Application), or the game engine platform. The resulting AR model (HBIM/HGIS model) will improve user experience and increase individual awareness of the ancient historic building existing in HDJ. The proposed system architecture employs the Autodesk cloud services platform, and supports and hosts our HBIM-HGIS integrated model.

6.3 System Design, Architecture and Modeling

Previously, we stated that 3D models of heritage architectural elements have been created with high levels of detail and geometrical accuracy, based on the prior collecting and processing of GIS datasets and using laser data to identify different components of an HBIM model through integrated BIM models into a GIS to provide georeferenced, seamless, and semantically complete information models. The 3D HBIM texture and geometry are directly transformed well and imported as one block through the integration process. Therefore, the determination in texture and geometry was solved and provided optimal results. The 3D BIM elements consist of semantically complete information models of the historic buildings whereas the users can access easily from anywhere and at any time, view, explore, interact, and manipulate from locally or internationally. Regarding the strategy developed for decision-making and querying, the matter will be valuable, if a decision support system is in place to allow users to extract information on the internal structure, contents, and history data from surrounding areas.

Regarding the application used, throughout the development of the model, Autodesk Revit has been the tool for HBIM extraction; and Esri ArcGIS desktop used for updating GIS data needed to obtain HGIS data and integrated with compatible interactive platforms used (Autodesk InfraWorks 360). However, we did not use the born-digital data, rather we focused on representing and structuring the historic data, both in graphical and non-graphical formats. In the interactive visualization implementation process, the integrated HBIM/HGIS 3D model is uploaded into a cloud-based service and stored as a library (Figure 6.1), which can be shared over URL links, while using cloud streaming to publish the historical information for interactive user experience.

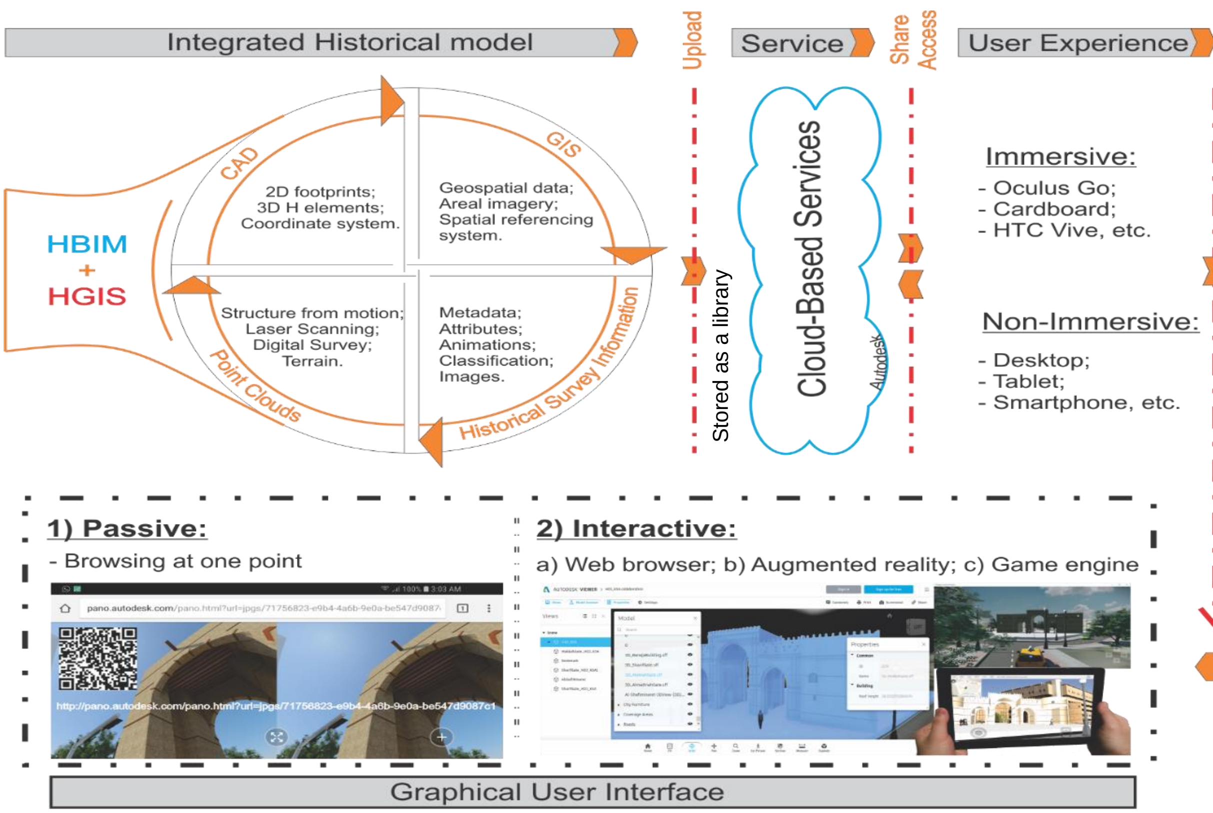

Figure 6.1: Visualization and User's Experience - System Design

In this study, we examine only the phase III (Development of an interactive user experience environment), according to the following steps;

1) Acquire AECO collection that was accomplished from previous phase I (HBIM and HGIS generation from the originally collected field data), and phase II (Integration of HBIM and

HGIS data and models to a common georeferencing system), represented by the integrated HBIM and HGIS model of the historic area. AECO collection includes a group of engineering programs, that can provide architecture designs, engineers, and contractors with a set of BIM and GIS tools that are supported by a cloud-based common data environment. This can facilitate the process of delivering the project; from the early-stage design, up to the construction. Benefits of this AECO collection include accelerating the design processes, enhancing the quality of the integrated workflows of documentation, and assisting in the processes of management, conceptual design, modeling, coordination, and documentation. Other benefits include exploring workflow by the industry, building the needed design, infrastructure of the design, and construction.

2) Create a passive user experience represented by the virtual display of the historic building models that are accessed through the obtained URL and- QR code reader.
3) Create an interactive user experience and share it publicly via AR and MR applications, and game engines.

Currently, we have an integrated historic BIM/GIS model that was created in the previous chapter by taking data processing to enrich semantic information. The Autodesk cloud service is a cloud-based platform for accessing a wide range of cloud services from basic editing to powerful rendering of models, which provides collaboration, and design for process management and information sharing of all phases in the product's life cycle. Critically, the said model was consumed into cloud-based services, to make the completely integrated model offering user experience visualization, embedded environment, and immersive or non-immersive queries with the scene. Hence, two visualization types are proposed; the Passive and the Interactive. The Passive Style enables users to access the models via URL links or QR-code reader applications at one location in 360°. The Interactive Style enables users to create their own experiences through either a web browser, AR (Consuming Application), or the game engine platform.

Therefore, we could meet our specified objects by:

1. Import the 3D model from the Integrating the HGIS and HBIM data represented the 3D library stored into Autodesk cloud service;
2. Obtain the URLs and QR codes for the five historic buildings to create 360° panorama viewings;
3. Establish an interactive web browser;
4. Generate virtual and augmented reality for interactive user experience;
5. Establish a Game engine application.

6.4 Graphical User Interface (GUI)

6.4.1 Passive Display

The passive display represents the VR user experience, which is used to build realistic viewing virtual environments, earning wide control of the experimental conditions and granting excellent ecological validity.

Therefore, the first step is identifying the VR standpoint. For building and acquiring virtual experience, both the InfraWorks 360 and NavisWork Manage Autodesk products were utilized. For establishing VR experience, the architecture engineering construction AECO collection must be available. The AECO collection is acquired from the integration of HBIM and HGIS for visualization of historic monuments.

The 3D model for the five historic sites of the historic district of Jeddah was exported to the InfraWorks 360. The five 3D models exported are Banaja Building, Almadina Gate, Sharif Gate, Makkah Gate, and Alshafi Minaret, whereas each one is exported in an individual fbx file. The FBX file is an Autodesk file of 3D drawings, such file extension used to create interoperability among 3D applications. Through exporting, it is essential to define the targeted area and ensure exporting materials, texture, GIS features, architectural features, and all objects merged in one texture. We use the Navisworks Manage Autodesk product, which is considered powerful management and controlling the environment of the construction projects of 4D and 5D while offering affordable tools for coordination, simulation, rendering, and analysis of the integrated projects. Within the Navisworks environment, we assigned the view standing point in the 3D model in each file, which identifies the point of view of a person in the virtual reality environment. In other words, this means considering the ability to look in all directions (i.e. 360° degree) as a Stereo Panorama feature of VR standing point.

The second step, after identifying the VR standpoint, is to render the stereo panorama of models or buildings, which is achieved by Navisworks. We set up the render on Autodesk cloud as a stereo panorama output and adjusted other parameters such as quality, width, exposure, and 3D view to their highest setting, which controls the VR exposure parameters. Once the rendering is complete, each site is converted to the VR mode, accessed by a URL link representing the 360° panorama view and the matrix barcode (Figure 6.2).

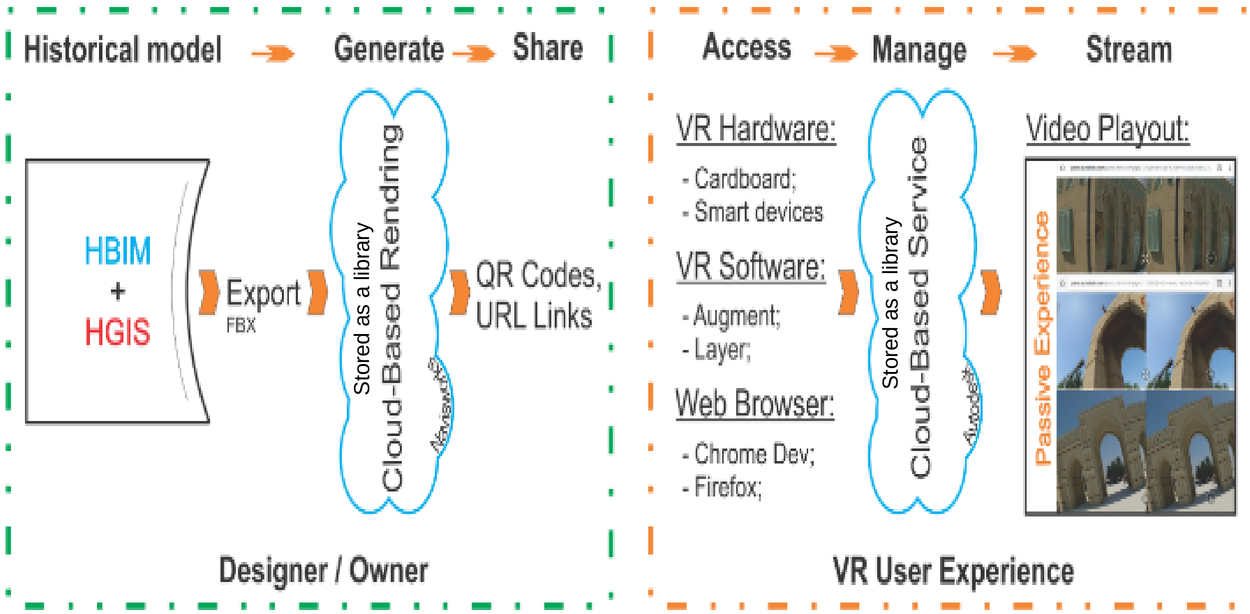

Figure 6.2: Workflow of Creating the Passive Display

To explain the elements of the previous workflow, (Figure 6.2), the integrated HBIM/HGIS has been taken and exported as FBX into the cloud-based service to render the scene and generate QR codes/URL links to be shared, which can allow users to embed into a scene and visualize it passively. Therefore, users can visualize the scene from one location viewing it in any direction. QR code for VR accessing by smart devices, the links, and QR code for five historic sights appeared in the previous (Figure 6.2), where the box on the left side represents the QR codes and the URL is the web accessing links. For exposure to the VR experience, the five sites can be accessed through these URLs or by some QR code reader apps, such as Layer, and Augment application.

6.4.2 Interactive Displays

Interactive displays enable users to immerse themselves in new digital environments and content. Interactive displays have many forms and schemes, in this project, the forms utilized for sharing experience publicly are a web browser, augmented reality, mixed reality, and game engine. Each one has its special features and its way of implementation that will be revealed in the next section.

There is discussion of "immersive technologies" and "interactive technologies." Technologies that enable people to actively engage and interact with digital content or virtual environments are referred to as interactive technologies. This can involve tools like motion tracking, gesture recognition, and touchscreens.

Conversely, immersive technologies are those that enable a user to feel present or immersed in a virtual setting. This can include technologies that give consumers the impression that they are physically present in a digital or virtual area, such as mixed reality (MR), augmented reality (AR), or virtual reality (VR).

Both immersive and interactive technology are covered in the author's writing. In the process of implementing HBIM/HGIS (Historic Building Information Modeling/Historic Geographic Information System) technologies, the author discusses the adoption and integration of all accessible immersive and interactive technologies.

6.5 Tools and Approaches

6.5.1 Web Browser

Shared View, which is essentially a web browser, provides a visual view of the 360° 3D model that is implemented on Autodesk InfraWorks 360. The main competence of the shared view is enabling the users to interact with an advanced feature to submit their feedback on the view progression, which designers can review. As known, the users' feedback is considered a viable resource to work on developments, and providing it in the early stages will simplify the review upcycle. Shared View is an online visualization that presents the utilized exposure 2D or 3D model publicly and gets feedback from users directly; thus any user will have the ability to put a review and comment online via the Autodesk Viewer. On a common basis, designers usually facilitate the communicating tools to the users where they can share their comments and feedback. The Shared View is a temporal visualization tool that enables the designers to expose their model within an expiration duration of 30 days; thus, our native designs or models are always protected. This benefits the authors based on a way of explicitly separating uncompleted work being shared for feedback purposes from more formal and permanent deliverables. The second step now is creating the URL link for web browsing views, which is obtained through the web administrator tools offered within the InfraWorks 360 environment. Web administrators have considered a control tool that enables designers to adjust and define the viewing conditions via the web browser. With this tool, designers could grant the public access to the model without restrictions, panorama view to high quality, scenario adjustments to render, and proposal sets as concept design (Figure 6.3).

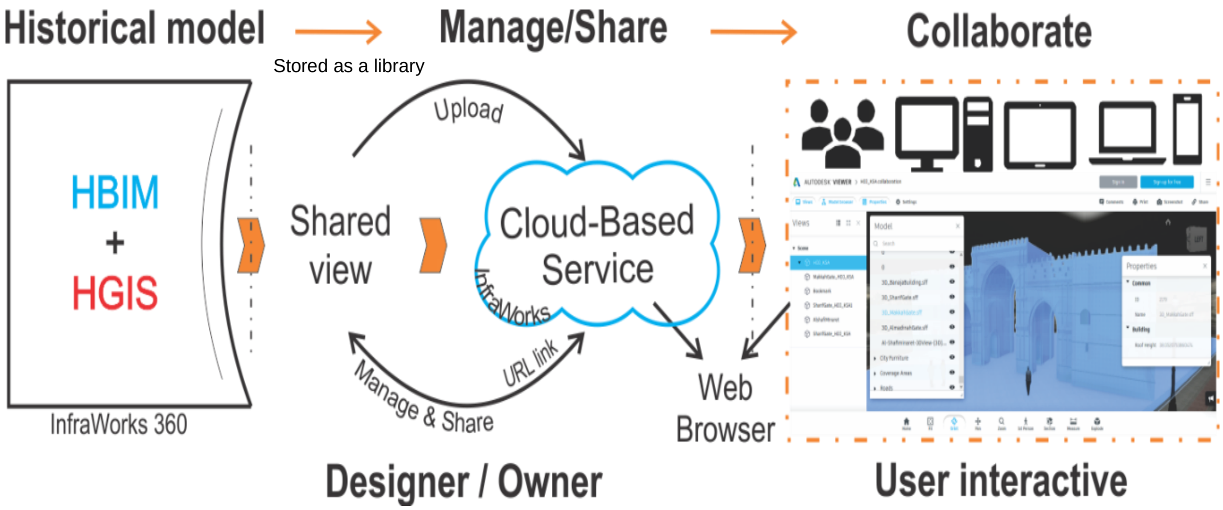

Figure 6.3: Web Browser-Based Interactive Experience

6.5.2 Augmented and Mixed Reality (AR and MR)

Augmented reality (AR) is used to enable navigation of the user position in real life, through the built model, walking around buildings based on the direction and orbits of the model on the iPad tablet application screen. The tablet can act as a virtual scene for the user's movements. Towards achieving this feature, InfraWorks exploited conjunction with a scenario.

The first step is to create a new scenario in the model considering the definition of the proper area of interest of the scenario and then update the cloud version of the models to synchronize all changes and scenarios created in the desktop version. The second step is to initiate rendering through web administration controls (Figure 6.4). This work shows the real-time orientation and tracking in the combined physical and virtual environments by merging the integrated HBIM/HGIS. The syncing service is completed through the cloud service on the model. Wi-Fi is used to ensure the connection between the App and the cloud service. The Global Positioning System (GPS) must be activated to detect the current location of the user. Such positioning information is critical in all heritage documents since it provides us with the needed indoor and outdoor information while illustrating the accurate position and orientation for the readers of the documents. Given the fact that our model is outdoor, we adopted BIM in this case, to provide essential information to resolve coordination issues during modeling, whether indoor or outdoor.

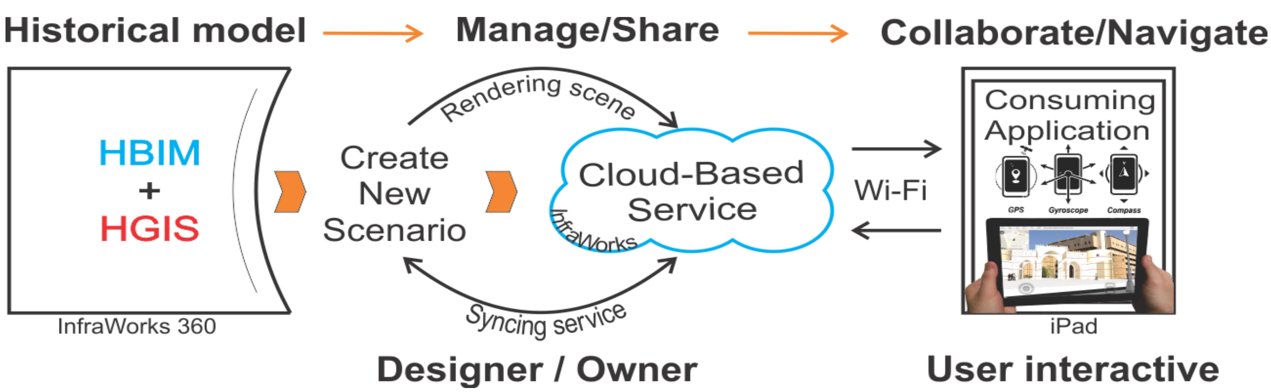

Figure 6.4: Augmented Reality-Based Interactive Experience

6.5.3 Game Engine

Game Engine is a video game designer platform, whereas these games are for consoles, mobile devices, and personal computers. It is used for integrating the merged HBIM/HGIS model and exploring AVR for user experience. Finally, interactive game engines, such as 3Ds Max interactive (Stingray) are tested and assessed for integrating HBIM and HGIS for a more interactive experience to users. This approach will allow users and game developers to convert the HBIM-HGIS model into a game interactive platform. To offer an improved and augmented VR experience to the users, the proposed methodology reflects our interest in using and integrating the existing interactive interface devices, according to the users' needs. Hence, we used 3Ds Max Interactive, to convert the critical integrated HBIM/HGIS model specifically, into a specified form, which enables the process of exploring the 3D model virtually while preserving the interactivity and most importantly, configuring it into the real-time engine.

The most significant advantage of the 3DS Max Interactive (real-time engine) is, referencing the external files, (e.g. models, textures, and scripts), while reloading the model dynamically instead of being embedded in full, especially after modifying the model. Moreover, the 3DS Max Interactive can import the geometry, in particular from the files of FBX, when importing the integrated HBIM/HGIS files into the real-time environment. However, we can clarify the way by which importing geometry can be progressively on-demand, along with the way by which populating the scene with interactive elements for querying HBIM/HGIS data which in turn is the key issue here. Initially, it is a typical challenge considering the used platform for hosting and sharing the HBIM/HGIS model. Addressing that, we used a cloud-based hosting service, in which the data can be uploaded, accessed, and streamed through enriched APIs (Application programming interface) to client applications (thin or thick) or other platforms. The model hierarchy, data properties, texture, and geometries are all imported in on-demand mode, meaning that with every spatial query, such as zoom in/out, panning, executing an identity on an element is a fact a URL call made to the server on cloud to stream that specific extend with associated data.

We used (COTS) application to model and implement the proof of concept. However, developers can customize and create other software layers on the top of the system, which have already been designed to actively interact with the HBIM-HGIS objects and their attributes to enhance workflows and application functionalities. This can be achieved by using data management and automation tools and reality capture API on the data layer tier and using a software development kit (SDK) as an application-oriented on the client application tier. Such a point is not part of the present research; however, most importantly in this study, we used a low-cost (COTS), by taking this high-end technology from the realm of specialized applications for providing a pervasive and cost-effective solution for interactive user experience, and to affordable practical examples of deployable information. Hence, the proof of concept has been achieved, as this research project is entirely about the design, development, and implementation of an HBIM-HGIS data model. This was achieved, whereas the model can be hosted on cloud web services (AutoDesk cloud) successfully, considering the ability of the application to use this REST endpoint.

Moreover, to clarify a specified strategy for the way by which one type of data source, such as GIS information, could be employed to query/expose another, such as image-based information, we comment that this is a case where this integration is about. Hence, the HBIM was enhanced using GIS information by adding GIS layers like Sea boundary, MasterPlan, building footprints, Province boundaries, StreetCenterLine, StreetCurb, and digital elevation model for the terrain generation to locate and geo-reference not only for the sake of querying accuracy of GIS assets but also every item from HBIM model associated with the GIS data and in the extend of the 3D boundaries. It provides the possibility to locate information for HBIM based on GIS information passed into a query. Settling upon that, it can also be deployed across different platforms, with little or even no overhead. Therefore, the 3D model can be exported as a stand-alone application onto handheld tablets running Android or iOS or even to Windows, playStation4 and Xbox. The following is a virtual representation of the game engine screen as illustrated in (Figure 6.5). Thus, more enhancements have been made by editing the historic model and then deploying it through a game engine on any aforementioned platforms.

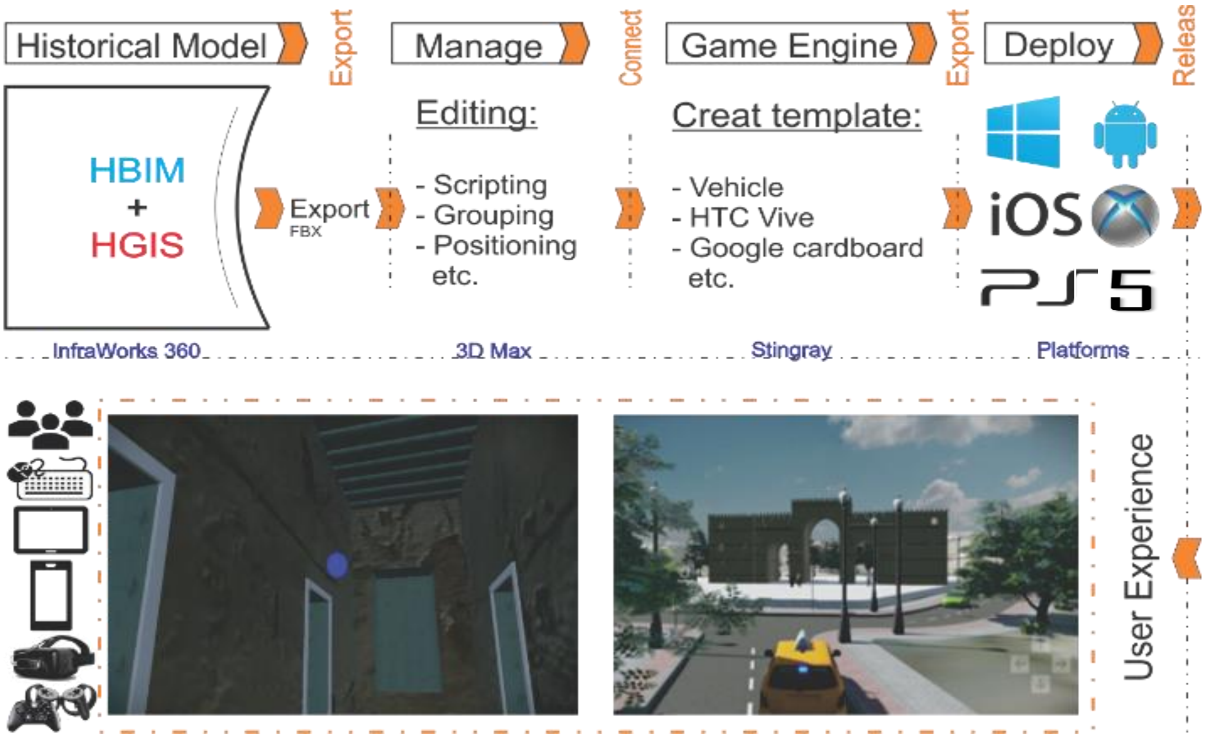

Figure 6.5: Game Engine-Based Interactive Experience

6.6 Interactive Visualization Implementation

We have uploaded the integrated HBIM/HGIS to the cloud service and managed the shared view to create URL links and share them over the cloud service on a browser for collaboration. Multiple users can deal/react with the scene at the same time interactively (with concurrent access to data).

Therefore, they can visualize, inquire, and provide feedback on the scene. In most cases, the cloud services play an important role in securing the shared data and helping users to collaborate through this service, focusing on the fact that, it is a cross-platform.

Hence, the requirement will now be simply a web browser, which is considered an advantage for this thin architectural model, which does not need any software or operating system installed on the user's devices.

After adjusting these parameters, the synchronizing was performed, and the URL link for the model on the web browser was obtained as follows: https://autode.sk/2L4Do1E. The URL link (Figure 6.6) considers the web browser link that can be shared over e-mails, social platforms, and so forth, where each user, who has the Link, can access the model while going through his/ her interactive experience.

The designer can control and grant access to any part of the historic integrated model (roads, buildings, imagery, and elevation) and their sub-elements (Windows, Doors, Roofs, Beams, etc.) supported by their information.

Figure 6.6: Rendering Output for the Historic Sites: QRcode and URL Links

Figure 6.7 reveals a screenshot of the Banaja building from one point, and various depths, observing the sophisticated accuracy and maintaining of all 3D model features including texture, geometrical features, and architectural features.

Figure 6.7: Banaja Building VR Scenes Screenshots

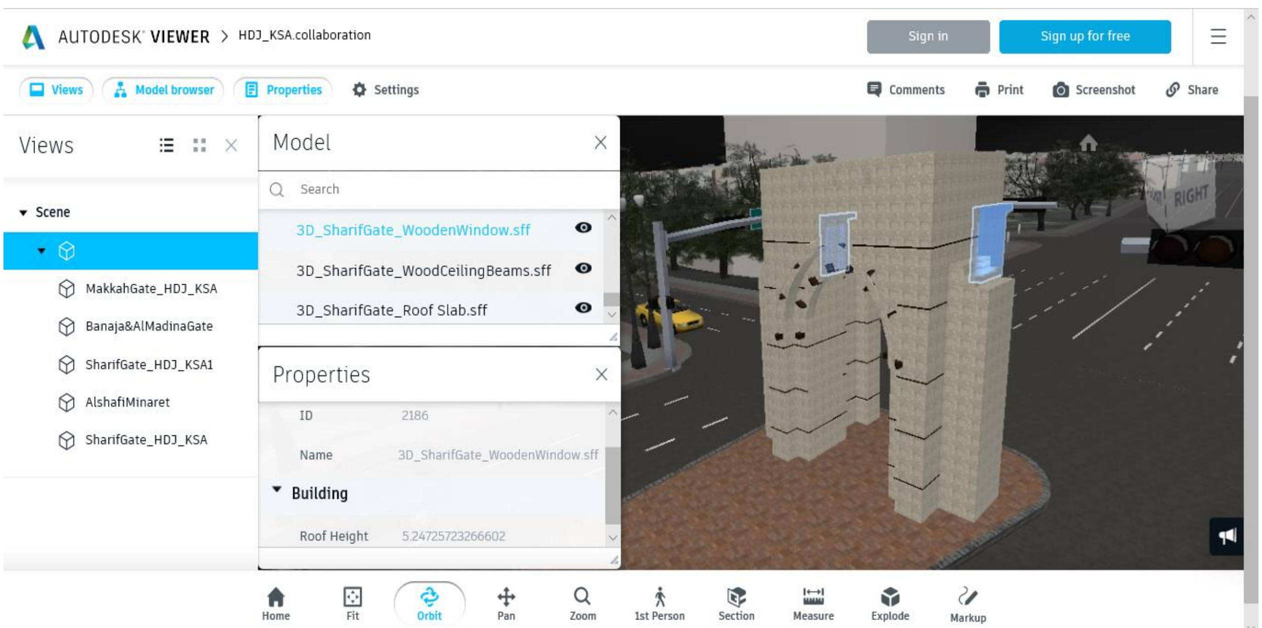

Figure 6.8: Layer Hierarchy Published On Cloud

Using Shared Views users, stakeholders, and designers can:

1- Quickly create online visual representations from within desktop application;

2- Easily create a link that can be shared with any stakeholders;

3- View the shared view and add comments and mark-up Via Autodesk Viewer (Figure 6.8);

4- Review comments and see the feedback they have received within the authoring application, and then respond.

The InfraWorks application has to be opened via iPad tablet, which includes a camera for tracking and navigation purposes in real time. Through the InfraWorks application position and orientation features are activated, enabling tablets to utilize the camera to track user position and match it to the corresponding points on the virtual screen of the model as illustrated in (Figure 6.9).

Figure 6.9: The Augmented Reality Screen of the Almadinah Gate Model

Furthermore, this work shows the real-time orientation and tracking in combined physical and virtual city environments, by merging the integrated HBIM/HGIS with interactive user experience tools as illustrated in (Figure 6.10).

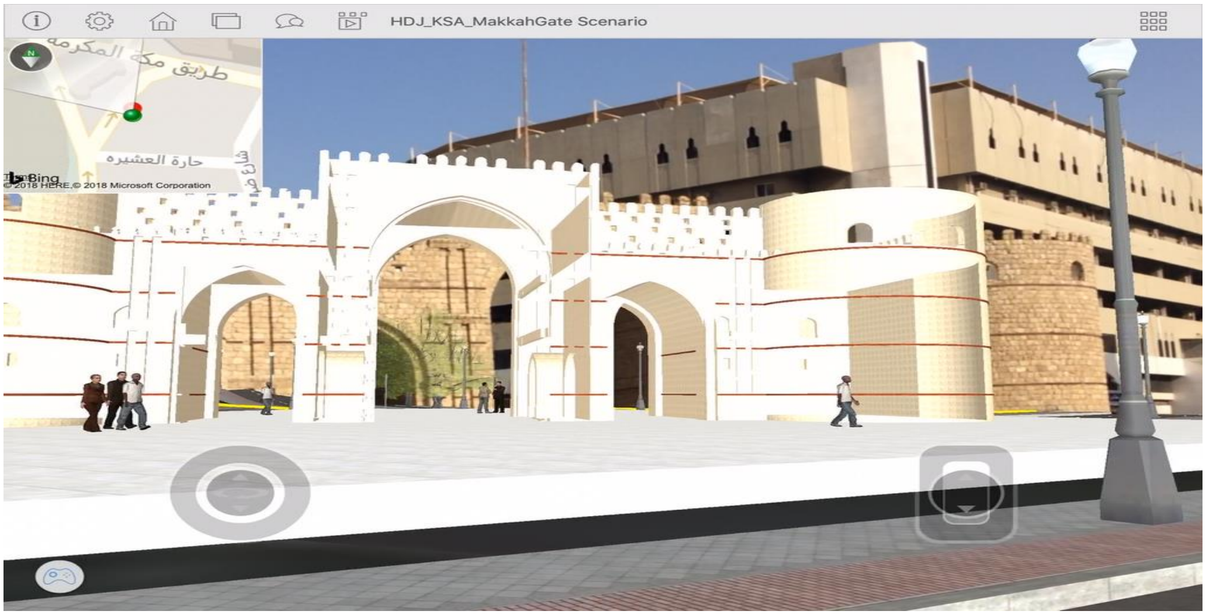

Figure 6.10: The Mixed Reality Screenshot of the Makkah Gate Model

6.7 Summary

The chapter discussed the visualization, interaction, and immersive environment. It explained the architecture and modeling, the concept of the user experience, the requirements according to the conceptualization of the user experience, the graphical user interface, and the used tools and approaches. The used tools and approaches included a web browser, AR and MR, and a game engine. At the stage of implementing the interactive visualization, the integrated HBIM/HGIS has been uploaded to the cloud service and managed the shared view to create URL links and share it over the cloud service on a browser for collaboration. Thus, we could merge the integrated HBIM/HGIS with interactive user experience tools as a valuable conservation method for the historic heritage of Jeddah.

Chapter 7 : Conclusion, Recommendations, and Future Research

The main conclusions of our study are compiled in this chapter, together with an analysis of their implications. We go over the original reasons we decided to do this study again and remind you of the goals, objectives, and research question. We also explore the theoretical underpinnings of our methodology, emphasizing the conceptual frameworks and modelling strategies used. Crucially, we address the knowledge gaps found in the current study and suggest ways to close them. The chapter then goes into detail about the project design process and the selected approach.

After that, we talk about the outcomes of this strategy. We highlight the project's distinctive contributions and the advances it makes to the field, while also admitting its limitations. In order to encourage more research in this field, the chapter ends with suggestions for future research directions.

7.1 Contributions

This study addresses the need for improved methods for conserving historic sites in Saudi Arabia, particularly those included in UNESCO's World Heritage List. As such, the aim is to increase accessibility to the digital data increase context-awareness of this site, and improve the users' spatial experience via portable and augmented reality (AR), and virtual reality (VR) devices while providing users' interaction with the explored 3D environment.

The literature review identified a gap in existing research on the application of digital tools for conserving historic sites in Saudi Arabia. While studies like (Bakri et al., 2012; Ferrari & Medici, 2017; Vacca et al., 2018) explored BIM/GIS integration for heritage conservation, these focused on sites outside the Kingdom. This, in turn, reflected the existence of only limited research conducted on the historic heritage of Jeddah sites in the Kingdom of Saudi Arabia (the adopted case study of this present research work) (Alitany, 2014; Baik et al., 2015; Ibrahim, 2018).

While appreciating the efforts of the previous researchers, this study addresses these gaps by proposing a novel method for heritage conservation that integrates HBIM, HGIS, and immersive technologies. This method utilizes readily available Commercial-Off-The-Shelf (COTS) software for cost-effectiveness and wider accessibility. The integration occurs in three key stages:

1. **Generating HBIM and HGIS:** This stage involves creating digital models of the historic site and its surrounding context using data from various sources, including the Jeddah historical databases.
2. **Integrating HBIM and HGIS:** This stage merges the HBIM and HGIS models, enabling users to explore information from both systems seamlessly. For example, users can query the model to find information about a specific building within its geographical context and vice versa.
3. **Interactive User Experience Environment:** The integrated model is then uploaded to a cloud-based platform, allowing users to access it through various interfaces, including immersive technologies like AR and VR. This enriches the user experience and facilitates exploration and understanding of the historic site.

The key contribution of this method lies in its ability to create a semantically complete HBIM-HGIS model that unlocks new possibilities for information retrieval and exploration. This integrated model, accessible through the cloud and immersive technologies, provides a valuable tool for supporting the conservation process, enhancing tourism experiences, and contributing to the knowledge base of architectural heritage. The contribution also includes the creation of the Jeddah dataset, which can be used by many and which can be updated to continue serving the conservation of the historic site of Jeddah.

Another gap is related to the applied techniques used by the previous researchers. Some of them adopted different techniques in their processes of conserving their targeted heritage sites to increase their digital accessibility, such as integrating BIM/GIS, either solely or via generating them with other approaches for creating and accessing the 3D model representation of the sites (HBIM/GIS) (Dore & Murphy, 2012; Vacca et al., 2018); 3D/HBIM (Chiabrando et al., 2016); BIM/ Virtual Tools (Ozcan-Deniz, 2019); HBIM/ Virtual Tools (Osello et al., 2018; Vacca et al., 2018).

Creating a robust, regularly updated dataset for the Jeddah Historic Site required collecting many data sources and integrating them with GIS to accurately map and refine the various data points. Involving local communities enhances cultural relevance while also verifying data quality. It is important that the construction of the dataset is documented and made available online. Continuous updates and maintenance, as well as capacity building through training and collaboration, ensure the feasibility of the dataset and its long-term usefulness in preserving Jeddah’s heritage.

7.2 Outcomes of the Study

Our study achieved significant outcomes by developing a novel method for cultural heritage conservation. This method integrates HBIM and HGIS using readily available software, creating a foundation for a cloud-based database. This database can serve various purposes in education and tourism.

We employed multiple spatial ETL tools and workflows from BIM and GIS platforms to achieve a seamless integration. Additionally, we conducted a comparative analysis of various ETL tools to ensure data accuracy and optimal performance. The study also explored the use of diverse and heterogeneous datasets for developing the HBIM-HGIS model.

A key achievement is the creation of a hierarchical 3D model with embedded semantic attributes. This model facilitates data exchange with various applications and provides access to real-time information through a cloud-based web service. Furthermore, we explored augmented reality and mixed reality techniques to enable users to interact with the HBIM-HGIS model and retrieve relevant information.

Our findings complement existing research on BIM/Virtual Tool integration and HBIM/Virtual Tool integration, such as the studies by Ozcan-Deniz (2019), Osello et al. (2018), and Vacca et al. (2018). The novelty of our approach lies in the integration of HBIM, HGIS, and interactive/immersive technologies within a single platform.

We utilized the latest technologies for data collection, ensuring the proposed approach's effectiveness in raising awareness of Jeddah's architectural heritage. The 3D models and interactive displays (including web browser access, a smartphone AR platform, and a game engine integration) enhance user experience through portable devices. This intelligent approach bridges the gap between the tourism industry and tourist needs by facilitating digital access to historic sites and fostering informed discussion.

7.3 Novelty and Benefits of the Study's Outcomes

The results and outcomes of this study hold promise for various fields, including:

- **Heritage Conservation:** Our approach demonstrates the potential of VR/AR technologies for heritage conservation. VR/AR can be used for virtual tours, raising public awareness, and training restoration workers.
- **Archaeological Research:** The 3D models with user-friendly interfaces can facilitate collaborative analysis and data sharing among archaeologists. This can lead to a deeper understanding of ancient architectural standards.
- **Tourism Industry:** The interactive 3D displays and easy access to information via various devices (PCs, smartphones, tablets) can significantly enhance the visitor experience at Jeddah's historic sites. This has the potential to increase tourist attraction and engagement.

7.4 Limitations of the Proposed Methods

This study acknowledges limitations related to the chosen methodology. Manually modeling complex historical elements in BIM software can be time-consuming and may not accurately represent their intricate geometries. This highlights the need for further exploration of automated or semi-automated tools for such tasks.

Another limitation is the software dependency during HBIM and HGIS integration. While some GIS data, like street centerlines, can be semi-automatically converted into 3D elements within InfraWorks 360, other elements may require manual adjustments for consistency within the virtual reality environment.

Limited access to relevant literature on the specific case study of Jeddah and the scarcity of existing digital documentation for these sites presented challenges. However, these limitations do not diminish the validity of the study's findings and their potential contribution to future research.

7.5 Recommendations for Future Research

Future research directions can further enhance the developed 3D integrated model and explore the potential of new technologies, while the following could be considered;

- **Data Integration:** Future research can explore the incorporation of additional datasets into the 3D model. This may include historical photographs, structural data, or material properties.
- **Advanced Technologies:** Emerging technologies like AI-powered object recognition within 3D models or real-time data integration from sensors can be investigated for their potential to enrich the user experience.
- **Evaluation and Refinement:** The efficiency of the tools and workflows used in this study can be systematically evaluated through user testing and performance benchmarks. This can inform the fine-tuning and optimization of the integrated model for future applications.

Furthermore, utilizing artificial intelligence (AI) and machine learning algorithms may present yet another way to improve the workflow. With the use of these technologies, data extraction, modelling, and analysis processes might be automated. This would speed up the process of creating accurate historical models and increase the effectiveness of heritage conservation initiatives.

We propose, as well, using City Geographic Markup Language (CityGML) as a rich multi-level dataset to represent 3D-GIS and IFC BIM (Industry Foundation Classes) modeling in the HBIM-HGIS integrated model. The IFC and CityGML data models, respectively, integrate Level of Development (LOD) and Level of Details (LOD) as a conservation process of historic heritage, whether in the Kingdom of Saudi Arabia or other countries. It is also suggested to explore and add other levels and model types, which are needed to make the data model more structured and consistent with the various users' application demands and needs. For example, the use of spatial-temporal datasets to complement model construction from maintenance to management. Moreover, there is a suggestion of looking into other ancient and historic heritages to be explored and modeled for modern digital norms by increasing the utilization level of powerful 3D modeling products and services to serve national identity sites and to provide sustainability and development over time. Overall, this study allowed us to elaborate significant universal guidelines, which in turn could be employed in the process of implementing HBIM/HGIS technologies with interactive and immersive technologies in other countries, too, while paving the road to the possibility of further editing and implementation of these technologies.

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Appendix I: Comparison between LSS and CRP coordinates of the same targets

Punts	Traditional Survey (m) Leica SmartWorx Viva			Close Range Photogrammetry (m) Sony a 65 Camera PhotoModeler Scanner S.W.			Residuals			RMS error
	X	Y	Z	X	Y	Z	dX	dY	dZ	
BW14	518926.539	2376894.207	5.866	518926.531	2376894.218	5.864	0.008	-0.011	0.002	0.013
BW02	518926.590	2376894.163	9.834	518926.583	2376894.160	9.835	0.007	0.003	-0.001	0.008
BW03	518931.161	2376894.494	9.883	518931.166	2376894.488	9.892	-0.005	0.006	-0.009	0.012
BW15	518931.167	2376894.500	5.798	518931.170	2376894.503	5.796	-0.003	-0.003	0.002	0.005
BW05	518931.551	2376899.553	9.797	518931.556	2376899.504	9.793	-0.005	0.049	0.004	0.049
BW17	518931.553	2376899.529	5.873	518931.559	2376899.473	5.881	-0.006	0.056	-0.008	0.057
BW16	518931.718	2376897.931	5.855	518931.718	2376897.89	5.861	0.000	0.041	-0.006	0.041
BW04	518931.761	2376897.851	9.829	518931.769	2376897.815	9.828	-0.008	0.036	0.001	0.037
BW18	518934.864	2376902.964	5.868	518934.851	2376902.909	5.870	0.013	0.055	-0.002	0.057
BW06	518934.868	2376902.980	9.789	518934.859	2376902.922	9.784	0.009	0.058	0.005	0.059
BW07	518939.393	2376907.609	9.739	518939.374	2376907.549	9.733	0.019	0.060	0.006	0.063
BW19	518939.415	2376907.626	5.865	518939.393	2376907.567	5.865	0.022	0.059	0.000	0.063
BW20	518942.672	2376910.975	5.847	518942.651	2376910.91	5.845	0.021	0.065	0.002	0.069
BW08	518942.691	2376910.981	9.737	518942.669	2376910.931	9.738	0.022	0.050	-0.001	0.054
BW21	518945.721	2376910.598	5.840	518945.685	2376910.517	5.838	0.036	0.081	0.002	0.089
BW09	518945.781	2376910.588	9.715	518945.769	2376910.508	9.701	0.012	0.080	0.014	0.082
BW11	518948.064	2376915.846	9.662	518948.061	2376915.844	9.672	0.003	0.002	-0.010	0.011
BW23	518948.114	2376915.741	5.826	518948.113	2376915.727	5.816	0.001	0.014	0.010	0.017
BW22	518948.418	2376912.415	5.875	518948.433	2376912.386	5.865	-0.015	0.029	0.010	0.035
BW10	518948.476	2376912.502	9.670	518948.495	2376912.482	9.681	-0.019	0.020	-0.011	0.030
Total RMS error							0.015	0.047	0.007	0.043

Appendix II: Comparison between LSS and TLS coordinates of the same targets

Points	Traditional Survey			Terrestrial Laser Scanning						RMS error
	Leica SmartWorx Viva			Leica Laser Scanner C10 Cyclone S.W.			Residuals			
	X	Y	Z	X	Y	Z	dX	dY	dZ	
BW14	518926.539	2376894.207	5.866	518926.530	2376894.205	5.866	0.009	0.002	0.000	0.009
BW02	518926.590	2376894.163	9.834	518926.583	2376894.161	9.834	0.007	0.002	0.000	0.007
BW03	518931.161	2376894.494	9.883	518931.156	2376894.489	9.882	0.005	0.005	0.001	0.005
BW15	518931.167	2376894.500	5.798	518931.162	2376894.496	5.800	0.005	0.004	-0.002	0.005
BW05	518931.551	2376899.553	9.797	518931.544	2376899.533	9.797	0.007	0.020	0.000	0.007
BW17	518931.553	2376899.529	5.873	518931.548	2376899.508	5.874	0.005	0.021	-0.001	0.005
BW16	518931.718	2376897.931	5.855	518931.731	2376897.933	5.855	-0.013	-0.002	0.000	0.013
BW04	518931.761	2376897.851	9.829	518931.773	2376897.855	9.830	-0.012	-0.004	-0.001	0.012
BW18	518934.864	2376902.964	5.868	518934.851	2376902.949	5.868	0.013	0.015	0.000	0.013
BW06	518934.868	2376902.980	9.789	518934.858	2376902.964	9.790	0.010	0.016	-0.001	0.010
BW07	518939.393	2376907.609	9.739	518939.376	2376907.599	9.738	0.017	0.010	0.001	0.017
BW19	518939.415	2376907.626	5.865	518939.396	2376907.616	5.865	0.019	0.010	0.000	0.019
BW20	518942.672	2376910.975	5.847	518942.648	2376910.969	5.848	0.024	0.006	-0.001	0.024
BW08	518942.691	2376910.981	9.737	518942.669	2376910.975	9.737	0.022	0.006	0.000	0.022
BW21	518945.721	2376910.598	5.840	518945.692	2376910.606	5.840	0.029	-0.008	0.000	0.029
BW09	518945.781	2376910.588	9.715	518945.755	2376910.596	9.716	0.026	-0.008	-0.001	0.026
BW11	518948.064	2376915.846	9.662	518948.062	2376915.845	9.663	0.002	0.001	-0.001	0.002
BW23	518948.114	2376915.741	5.826	518948.113	2376915.739	5.826	0.001	0.002	0.000	0.001
BW22	518948.418	2376912.415	5.875	518948.419	2376912.414	5.875	-0.001	0.001	0.000	0.001
BW10	518948.476	2376912.502	9.670	518948.477	2376912.502	9.670	-0.001	0.000	0.000	0.001
Total RMS error							0.014	0.009	0.001	0.011