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A Comprehensive Heritage BIM Methodology for Digital Modelling and Conservation of Built Heritage: Application to Ghiqa Historical Market, Saudi Arabia

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Abstract: Preserving historical architectural structures is crucial for safeguarding cultural heritage. This study explores the application of Heritage Building Information Modelling (HBIM) to enhance the documentation process of the Ghiqa Historical Market in Saudi Arabia, a monument known for its intricate architecture and cultural significance. Traditional documentation methods often fail to capture detailed features accurately and rely on labour-intensive manual processes. HBIM uses advanced digital technologies to improve precision, efficiency, and preservation efforts. In this study, point cloud data from 3D laser scanning is used to create a detailed digital model of the market, covering structural systems, material attributes, architectural features, and historical context. The research also integrates historical archives and photographs to enrich the model with additional contextual information. This comprehensive approach provides a holistic understanding of the Ghiqa Historical Market, aiding accurate preservation and restoration decisions. HBIM offers several advantages in architectural documentation. The digital model enhances visualization, allowing stakeholders to explore the site from multiple perspectives. It also serves as a tool for analysing structural integrity, identifying potential risks, and planning restoration interventions. Moreover, digital documentation ensures effective knowledge transfer across generations, preserving valuable architectural heritage for future reference and research. Additionally, it promotes interdisciplinary collaboration among architects, historians, conservators, and other stakeholders involved in preservation. Including the Ghiqa Historical Market in the UNESCO World Heritage List would highlight its global significance, attracting international attention and resources for its preservation. This designation would underscore the market's cultural and historical importance, fostering a sense of pride and responsibility in its maintenance. The implementation of Heritage BIM demonstrates its potential to revolutionize heritage conservation by combining diverse data sources into a single, detailed, and accessible digital resource.



Citation: Baik, A. A Comprehensive Heritage BIM Methodology for Digital Modelling and Conservation of Built Heritage: Application to Ghiqa Historical Market, Saudi Arabia. *Remote Sens.* **2024**, *16*, 2833. <https://doi.org/10.3390/rs16152833>

Academic Editors: Rui Marques, Claudia Mondelli and Maria Giovanna Masciotta

Received: 18 June 2024

Revised: 29 July 2024

Accepted: 30 July 2024

Published: 2 August 2024

Keywords: HBIM; 3D laser scanning; historical architecture; documentation; conservation; Ghiqa Historical Market; Saudi Arabia; cultural heritage

1. Introduction

Cultural heritage has enormous and immeasurable importance for communities. Unfortunately, this fact is sometimes not realized until there is a risk of damage or destruction. Several factors, including weather and community awareness, can contribute to these potential dangers. As a result, various studies have been conducted to provide methods that can assist in preserving historical sites [1]. Documenting historical architecture requires a multidisciplinary approach that includes traditional disciplines like architecture, survey methods, art history, and history, as well as digital microelectronics, computer science, and information science. Therefore, to avoid losing focus, it is important to prioritize preserving and reworking monuments in digital media over physical preservation efforts [2]. Architectural documentation is an essential technique for heritage site protection and interpretation.



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While written reports, sketching, and photos are all useful forms of traditional documentation, they are not always effective in illustrating the finer points and complexities of historical buildings. Moreover, they fall short of utilizing the full potential of cutting-edge technologies to produce thorough and engaging representations [3].

In recent years, the field of architectural documentation has witnessed significant advancements via the integration of Building Information Modelling (BIM) technologies. The concept of BIM has revolutionized the way architectural information is generated, stored, and analysed, allowing for more efficient design processes and better project outcomes. Nowadays, virtual 3D models are commonly utilized to document historical places. These models are efficient for reconstruction and restoration, and they provide rich information resources to researchers from numerous fields [4].

BIM is a comprehensive process for the design, representation, construction, and the long-term management of the built environment. BIM packages allow project partners to collaborate on design and facilities management by combining multidimensional visualization with complete, parametric databases [5]. When it comes to integrating different data input, such as laser scanning, photogrammetry, archival research, and expert knowledge, BIM has gained significant traction over the past few years. Commentators, software program vendors, and some professionals have adopted it as the new design and management process for different industries, i.e., the Architecture, Engineering, and Construction (AEC) industry. Moreover, BIM marks a profound revolution in the management of architectural information from initial design to the end of a building's lifecycle [6].

Using Heritage Building Information Modelling (HBIM) in cultural heritage management and conservation projects holds tremendous promise for efficiency due to its numerous benefits. To begin with, the concept of interoperability offers an interactive and immersive digital platform that enables the involvement of different experts and facilitates data sharing, thanks to the functionality characteristic of HBIM software programs, for example, Autodesk Revit and Navisworks. While usability refers to how user-friendly and easy to use the software is, interoperability is about the software's ability to work with other systems and share information effectively. This not only helps improve comprehension but also allows for informed decision-making during restoration and conservation. In addition, HBIM preserves the architectural legacy in digital form, making it a dependable archive tool. This guarantees that even in the event of physical damage or destruction, future generations will be able to access and study the intricate details of historical sites, in our case the Ghiqa historical market. Furthermore, HBIM facilitates the tracking of treatments and the organization of restoration phases, creating a distinct and searchable archive [7].

The purpose of this scientific paper is to investigate the utilization of HBIM as a powerful process for enhancing the architectural documentation process of heritage buildings, with application to the renowned Ghiqa Historical Market in Saudi Arabia. Moreover, it aims to investigate the utilization of Geographic Information System (GIS) as an effective technique to analyse the data of the heritage site. The Ghiqa Historical Market is extremely important culturally and historically, acting as a tribute to the region's rich history. However, like many historical constructions, it faces various obstacles in terms of preservation, restoration, and correct recording. By adopting HBIM techniques, we can overcome these challenges and generate a comprehensive and accurate digital representation of the Ghiqa Historical Market.

In this scientific study, we will examine the procedure used to create the Ghiqa Historical Market's HBIM model, emphasizing the methods for acquiring data, strategies for integrating data, and difficulties encountered. Also, this study will examine the future directions and possible uses of HBIM in the context of Saudi Arabia's historical site preservation and architectural documentation. By using technology and embracing HBIM, we can not only overcome the constraints of traditional documentation methods, but also pave the way for a more sustainable and informed approach to the preservation of our heritage. To establish a stronger link between the past and the future, the Ghiqa Historical Market

case study will serve as evidence of the enormous significance that HBIM holds in the documenting and understanding of historical structures.

1.1. Ghiqa Historical Market—Saudi Heritage

Saudi Arabia has a rich cultural legacy, including several historical landmarks that highlight the country's vibrant past. Among these treasures is the famous Ghiqa Market, which is located east of Badr Governorate in the Medina region. Dr. Ahmed Al-Numani indicated that the "Ghiqa" site was well-known among historians as a commercial station with a thriving market until 1360 AH, when convoy transportation was cut off due to the appearance of cars [8]. Figure 1 shows an example of Ghiqa Market's buildings. The historic Ghiqa Market holds a significant place in the collective memory of the Kingdom of Saudi Arabia. It is the location of the most well-known wells, the Ibn Hasani wells, which are regarded as one of the most famous caravan stations used by pilgrims while traveling between Mecca and Medina. Due to its significance at the time, the road via Ghiqa was known as the Royal Road. Convoys of pilgrims traveling from Mecca to Medina took one of four routes depending on the dependency of the pilgrim; Al-Sultani is the most water-filled and well-travelled path during the migration [9]. Ghiqa was well-known for its enormous commercial market, which contained many stone-built stores with palm leaf roofs, most of which are still intact today. The market sold a wide range of items, attracting a considerable number of people from nearby villages and towns, as well as those traveling through the area [10]. Like many historical sites, the Ghiqa Historical Market must deal with several obstacles that might threaten its long-term existence and preservation. Urbanization, deterioration, and insufficient documentation are some of the factors that seriously threaten its architectural integrity. Thus, it is essential to use advanced architectural documentation strategies that exceed traditional approaches in order to preserve and document the irreplaceable past placed within this historical treasure [11].



Figure 1. Historic Ghiqa Market buildings. The Ghiqa Historical Market, located in the Medina region of Saudi Arabia.

1.2. Heritage Sites Challenges in Saudi Arabia

Saudi Arabia is home to numerous cultural heritage sites that reflect the country's rich history and different cultural traditions. These sites, which range from ancient archaeological ruins to historical cities and traditional villages, provide physical links to the past while also providing insights into the region's cultural, architectural, and socioeconomic evolution. However, the documentation of these unique heritage assets poses a multiplicity of issues that must be solved to ensure their preservation and promotion [12]. Documenting heritage places is critical for understanding, conserving, and passing on their significance

to future generations. It entails documenting and preserving the physical characteristics, historical context, and cultural values linked with these sites [3]. In Saudi Arabia, balancing urban expansion with the protection of cultural heritage involves numerous trade-offs. The cultural heritage value of a site may be reassessed in light of significant economic pressures as well as changing preservation priorities. The tension between development and heritage preservation poses long-term challenges for Saudi heritage sites and preservation efforts. While a sustainable development method for World Heritage Sites (WHS) is crucial, several factors in Saudi Arabia complicate effective documentation [13]. Saudi Arabia's rich and varied cultural legacy is one of the main obstacles. The country is made up of an extensive region with several different parts, each having its own special historical landmarks. From the rock art of Jubbah and the Nabatean city of Madain Saleh to the mud-brick architecture of Diriyah and the old town of Jeddah, Saudi Arabia has a rich tapestry of cultural history that necessitates extensive documenting efforts [12]. Furthermore, many heritage sites are located in remote and often inaccessible areas, which complicates documentation. Some sites are in deserts, mountains, or coastal areas, which presents logistical problems for data collecting and analysis. Accessibility problems, limited infrastructure, and harsh environmental conditions can all limit on-site documentation and data collection [14]. Moreover, maintaining the intangible legacy linked with these locations presents its own set of issues. Traditional crafts, performing arts, oral traditions, and social customs are all integral parts of Saudi Arabia's cultural legacy. Documenting and protecting these intangible features necessitate new methods that extend beyond the documenting of physical structures. Another difficulty is the protection and conservation of heritage sites. Many sites suffer from neglect, urban expansion, natural decay, or a lack of adequate preservation. The lack of detailed documentation reduces conservation planning and restoration efforts, as inaccurate records and data can lead to poor decision-making. Due to the substantial trade-off between conserving heritage sites, accommodating population growth, and the economic drive for urban expansion, the value of heritage sites may be reevaluated amidst the increasing pressures of urbanization, considering the Kingdom of Saudi Arabia's economic and cultural preservation aims [15]. Furthermore, the documentation of heritage sites in Saudi Arabia necessitates collaboration and coordination among numerous stakeholders, including government agencies, researchers, local populations, and foreign organizations. Effective communication, knowledge exchange, and the construction of comprehensive databases are critical for achieving a cohesive strategy for documentation and preservation [16].

1.3. The Aim

In this scientific study, we investigate how advanced processes, for example, BIM, terrestrial laser scanning, and photogrammetry can help with the Ghiqa Historical Market's architectural documentation process. These cutting-edge procedures allow for the production of precise, detailed, and interactive 3D digital models that represent not only the physical characteristics of the market but also its historical and cultural significance. Also, the study emphasizes the significance of architectural documentation in maintaining and promoting Saudi Arabian history by utilizing this advanced method on the Ghiqa Historical Market. Moreover, integrating cutting-edge technology with collaborative efforts would highlight Saudi Arabia's architectural treasures, such as the Ghiqa Historical Market, which would be valued and honoured for many years to come.

Researchers, architects, and conservationists would use BIM and other new technology to more precisely and efficiently document, analyse, and restore the Ghiqa Historical Market. Digital models would be used in order to present informed decisions about conservation and renovation activities. Furthermore, the virtual representation would serve as an immersive platform for researchers and the general public to study and interact with the market's architectural and cultural heritage, cultivating a greater understanding of Saudi Arabia's rich history. Furthermore, the application of architectural recording techniques aids in the preservation of Saudi heritage beyond its physical form. Digital

models and databases would be essential archive resources, ensuring that knowledge and understanding of the Ghiqa Historical Market are preserved and shared with future generations. These digital archives provide a strong means of protecting the market's past, even in the face of potential challenges like natural disasters or urban growth.

In the following sections, the study will explore the methods used to record the Ghiqa Historical Market, going over the methods for gathering data, the difficulties encountered, and the potential uses for the digital models. By adopting architectural documentation, citizens and visitors can respect Saudi Arabia's rich cultural tradition and advance a deeper comprehension of our shared past.

1.4. The Research Contribution

This paper significantly advances architectural documentation and heritage preservation by employing Heritage Building Information Modelling (HBIM) to document the Ghiqa Historical Market in Saudi Arabia. The study's originality lies in its comprehensive methodology, integrating traditional architectural documentation procedures with state-of-the-art digital technologies, for instance, 3D terrestrial laser scanning and photogrammetry. HBIM enhances the accuracy and efficiency of documenting the market while integrating contextual data from historical photos and archives into the digital model.

A notable aspect of this research is its emphasis on utilizing HBIM for precise conservation and interpretation of architectural heritage. By employing advanced digital tools, the study facilitates interdisciplinary collaboration among stakeholders and supports informed decision-making in preservation and restoration projects. Additionally, integrating Geographic Information System (GIS) analysis with the HBIM model provides valuable insights into spatial relationships and structural integrity, further enhancing the understanding and management of the site.

Moreover, the research highlights the importance of leveraging technological advancements to protect Saudi Arabia's cultural legacy. Focusing on culturally significant landmarks like the Ghiqa Historical Market, the study aims to contribute to the UNESCO World Heritage List nomination process by ensuring meticulous documentation and preservation of these invaluable cultural assets.

2. Literature Review

2.1. 3D Reality Capture Technique in Heritage

The heritage building can be digitally represented using 3D reality capture techniques, which collect detailed 3D data on the structure. Among these methods are laser scanning and photogrammetry. Laser scanning accurately captures the 3D data of a building's surface geometry, such as walls, roof, windows, and other features, by emitting a laser beam that reflects off these surfaces. The scanner's sensor detects the reflection and measures the distance between the scanner and each point on the building's surface [17]. Photogrammetry processes photographs of the site or object taken from several perspectives to generate a 3D model of the object surfaces, using either a ground-based camera or a drone-mounted camera [18]. Moreover, Structure from Motion (SfM) generates a 3D model by combining multiple photos taken from different angles [19].

Furthermore, it is essential to distinguish between photogrammetry and Structure from Motion (SfM). Photogrammetry involves the acquisition of multiple photographs from different angles to generate accurate 2D or 3D representations of objects or spaces. This method relies on precise measurements and the geometric configuration of the camera setup to triangulate points in space. In contrast, SfM is a more flexible and automated technique that generates 3D models from unordered image sets by identifying common features in overlapping photographs and estimating the camera positions and orientations [20].

The utilization of these methods offers complementary advantages. Photogrammetry provides high precision and is particularly effective for capturing detailed textures, making it ideal for applications requiring high-fidelity visual representations. SfM, while slightly less precise, is highly efficient in generating 3D models from large image sets, making it

suitable for extensive and complex environments [20]. The integration of both methods can enhance our capability to accurately document and analyse architectural and archaeological sites, offering a comprehensive approach to digital reconstruction and preservation [21].

Once the data is collected, it can produce detailed engineering information, for example, drawings, maps, and other visual aids illustrating the building's geometry, measurements, and surface properties. Potential issues could be identified through the collected data, for instance, deformations, cracks, or damage, that may not be visible during visual inspection. Additionally, 3D reality capture can simulate various scenarios for decision-making and generate a digital twin of the heritage site for continuous monitoring and analysis [17].

Heritage site preservation and documentation is an essential endeavour that helps us to preserve our cultural heritage for coming generations. Photographs, drawings, and written descriptions—conventional documentation methods—have proven useful in preserving the physical characteristics of heritage monuments. Nevertheless, these techniques frequently fail to capture the rich intricacies and immersive experience of these locations. This is where the use of 3D reality capturing technology has changed the experience for heritage documentation [7].

One of the primary advantages of 3D reality capture is the capacity to generate detailed digital reconstructions of historical sites. Using techniques like photogrammetry and 3D laser scanning, high-resolution images and point cloud data are captured to create accurate 3D models. These models can serve various purposes depending on the project's scope, including immersive digital reconstructions that allow users to virtually explore and interact with heritage sites as if physically present [22]. However, immersive reality is just one of the many outcomes of 3D reality capture. The comprehensive 3D models also provide a precise and thorough record of heritage sites, which is crucial for preservation and restoration efforts. By analysing these models, architects and conservationists can assess the current condition of a site, identify areas of deterioration, and plan necessary conservation actions. This detailed data enhances the effectiveness of restoration projects and supports well-informed decision-making [23]. Furthermore, 3D reality capture plays a significant role in digital documentation. These digital models serve as repositories of knowledge accessible to scientific researchers, historians, and the public. Digital archiving ensures the long-term conservation of the heritage sites by reducing the risk of physical damage, deterioration, or loss over time [24]. It also enables remote access, expanding research and educational opportunities to a broader audience [22]. The 3D reality capture methods transform our ability to document, preserve, and share cultural heritage. This technology offers unprecedented opportunities for accurate documentation, immersive exploration, and informed conservation planning, thus revolutionizing the preservation of our cultural legacy [23].

2.2. Aerial and Close-Range Photogrammetry

Building documentation techniques have shifted from 2D to 3D due to the enormous development of digital technologies in this field. The effectiveness of photogrammetry in terms of time, cost, accuracy, and utility has led to a rise in the use of 3D digital modelling. Close-range photogrammetry is becoming more and more important in today's world of historical building data collection [25]. Point clouds which are produced by terrestrial laser scanning (TLS) and close-range photogrammetry (CRP) serve as the foundational stage of data capturing; each of these points has "x, y, and z coordinates" based on the scanned surface. Scan to BIM refers to the process of capturing precise spatial data through laser scanning to create detailed point clouds, which are then converted into BIM. This workflow allows for the analysis and integration of the captured data into comprehensive 3D models, facilitating various stages of design, construction, and development [26]. Recent advancements in sensor technologies have sparked renewed interest in close-range photogrammetry as a method for gathering reality-based 3D information. Furthermore, close-range photogrammetry is now a feasible, low-cost technology for 3D mapping thanks

to the significant democratization of UAVs (Unmanned Aerial Vehicles), also known as drones [27].

2.3. Terrestrial Laser Scanning “TLS”

The 3D Terrestrial laser scanning is an automated measurement approach. This approach is used to determine the 3D coordinates of an object’s surface. This approach involves emitting laser beams toward the surface, which then reflect back to the scanner. The resulting data is provided in point cloud format, with each point assigned x, y, and z coordinates from the scanned surface, creating a highly detailed 3D representation [17]. Moreover, several laser scanning technologies are available in the technical industry, primarily utilizing three types of scanner technologies: Time-of-Flight scanners, triangulation, and phase comparison. Time-of-flight scanners gauge distances by measuring the time taken for a laser pulse to travel to the object and return, making them ideal for long-range measurements [18]. Triangulation scanners project a laser beam onto the object and use a camera to capture the reflection, calculating distances based on the angle of return, which is ideal for high-precision, short-range scanning. Phase comparison scanners measure the phase shift between the emitted and reflected laser beam, offering high accuracy over medium distances [28]. These technologies are particularly suitable for metric heritage studies, enabling the capture of detailed geometrical data of heritage structures. This data can be used for various applications, including creating accurate digital models for preservation, restoration planning, and virtual reconstruction [29]. Moreover, the detailed point clouds can help identify structural issues, for instance, cracks as well as deformations, that may not be visible during a visual inspection, and facilitate ongoing monitoring and analysis [30]. Furthermore, the difference between these scanning technologies depends on how the scanner calculates 3D coordinate measurements. In triangulation-based scanning, laser beams are directed onto the surface of an object and captured by one or more cameras [31]. According to [32], “time of flight scanners calculate the range, or distance, from the time taken for a laser pulse to travel from its source to an object and be reflected back to a receiving detector”.

2.4. Terrestrial Laser Scanning Data Processing

The point cloud data is a type of output data that is obtained through 3D laser scanning and represents a range of 3D coordinates. A specialized program is required to handle the massive volume of data pertaining to point cloud data (Figure 2) for example, Leica Cyclone 360 v.2023. Furthermore, while it often only takes a few minutes to capture several millions of precise 3D points, it takes a great deal of labour to convert the laser scanning data into a 3D model that contains useful information [33]. Many software programs on the engineering market can handle point cloud data, such as Polyworks, Leica CloudWorks, RiScanpro, and Autodesk ReCap. These programs have significantly enhanced the handling, modification, and analysis of vector and image information derived from point clouds. They integrate methods for triangulation and point cloud surfacing [34].

Once the scanner point cloud data has been transmitted, several software programs are available to troubleshoot and remove noise or distortions. These programs are essential for ensuring the accuracy and quality of the 3D model, offering functions such as filtering algorithms to eliminate random noise, techniques to correct systematic errors, and features for aligning and merging multiple scans. Advanced software can also classify and segment point clouds, distinguishing between different materials and surfaces, which is particularly useful in complex environments. By refining the raw data, these programs enhance the precision of measurements and the overall reliability of the digital representation. These laser scanner systems also come with individual software packages. For example, Leica Cyclone® is the primary software for the laser scanning system produced by the Leica company. The goal of Leica Cyclone 360® is to take point cloud data and create an object with the best possible shape. Additionally, users can choose from several object-specific utilities within Leica Cyclone® based on the topology of the scanned point cloud [35].

Moreover, different software applications are used in place of polygonal 3D models, such as editable feature-based CAD models or NURBS surface models [36].

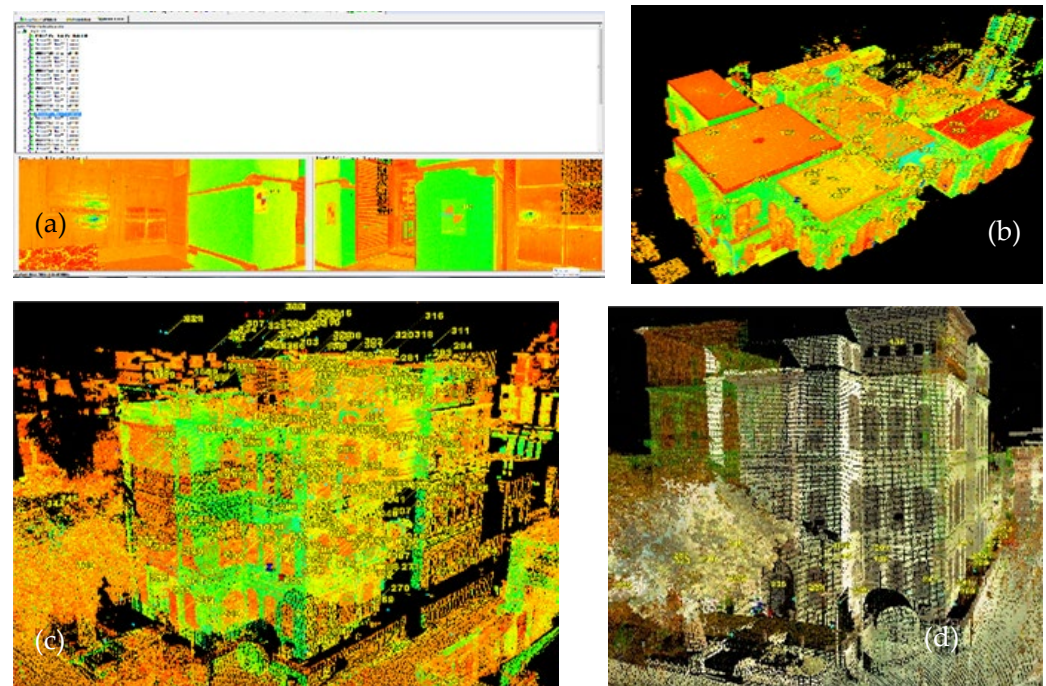


Figure 2. Previous project for Point Cloud Data processing. (a) Shows the registration of the scan, (b) Applying the image texture map. (c) The 3D point cloud model after registration. (d) The 3D point cloud after adding the image Batch [11].

2.5. Combining Laser Scanning and Digital Images

Most modern laser scanning systems include a built-in camera for capturing image data. Additionally, stacks of multiple photos can be used to colorize 3D point clouds. This involves mapping RGB colour data from images to range data, considering point translation, instrument rotation, and perspective projection [37]. Achieving accurate colour mapping requires precise geometric calibration of both the laser and the camera, including adjustments for camera lens distortion. Aligning and correcting viewpoints captured in images is essential when mapping to a point cloud. Furthermore, with knowledge of the camera's position and orientation within the geometric model's coordinate system, a High Dynamic Range (HDR) colour image can be precisely applied to the geometric model represented by the point cloud [28].

2.6. Building Information Modelling (BIM) in Cultural Heritage

Information and communication technology (ICT) was integrated into building industry operations, leading to the creation of BIM. Ever since, the construction industry has recognized it as an engine behind innovation and increased production. It was also created to address issues with cooperation, handling large amounts of information, reducing project duration and expense, and enhancing construction efficiency [38]. The fields of architectural survey, building, conservation, and restoration have benefited greatly from advanced techniques such as BIM in several ways. It is now possible to document the current state of building construction with effective, quick, non-invasive, and most importantly, highly precise techniques. This allows for further thorough research, more precise treatments, and an accurate record of the building in its original condition [39]. HBIM is the process of employing BIM techniques and knowledge to generate a 3D digital model of a heritage building or structure. Data on the architecture, structure, materials, and history of the heritage building, as well as information on its present state and maintenance requirements, can all be included in this representation [35].

Creating an HBIM through scan-to-BIM processes enables seamless integration of buildings into workflows for heritage studies [29]. This approach not only facilitates the preservation and documentation of historical structures but also harnesses the full spectrum of benefits that BIM offers, including enhanced collaboration, accurate visualization, and efficient management throughout the building's lifecycle [39]. In addition, HBIM is a 3D interactive engineering model that represents an interactive solution. Typically, architectural photogrammetry, as well as terrestrial laser scanning data (TLS) are the foundations of this 3D HBIM (Figure 3) and can be described as level of details (LoD 0) [33]. Furthermore, sections, 3D models, orthographic views, and comprehensive technical drawings are all automatically provided by HBIM. HBIM may assist the heritage preservation and conservation fields in a number of ways, including enhancing knowledge of heritage buildings and their context, understanding heritage building materials and having a solid understanding of construction and structural procedures as well as building pathologies [17]. Furthermore, HBIM facilitates comprehensive assessment of proposed restorations and adjustments before final decisions are appointed. This capability supports the maintenance of heritage buildings by aiding in budgeting for repairs and maintenance. Additionally, it enhances public engagement by enabling remote viewing of models through a free viewer application, thereby offering broader accessibility and interaction with historical building information [29]. Also, by presenting the cultural heritage knowledge of heritage buildings, the chance to obtain data about the object's building processes and material makeup is also provided. During the HBIM process, the prototypes of parametric libraries are modelled onto the point cloud data and the photogrammetry within the implementation of several software platform management strategies [17].



Figure 3. Previous project of HBIM model for Nasif House [11].

Several notable projects exemplify the application of HBIM in cultural heritage conservation. For instance, the HBIM pipeline developed for the conservation of the city walls of Pisa demonstrates how large-scale architectural heritage can be documented and preserved with precision. This project utilized advanced laser scanning and photogrammetry techniques to create detailed 3D models of the city walls, which allowed for an accurate assessment of their current condition and the identification of areas requiring restoration. The comprehensive digital documentation enabled conservationists to plan and execute preservation efforts with greater accuracy and efficiency [40].

The “CHARMING PISTOIA” research project integrates HBIM for the preservation and maintenance of heritage structures, showcasing an effective methodology for managing historical buildings. This project involved the creation of an HBIM model for the city of Pistoia, which included detailed information on the architectural and historical significance of the buildings. The integration of HBIM in this project facilitated the development of a structured approach to maintenance and conservation, ensuring that interventions were based on precise data and historical context. The project also highlighted the potential of HBIM to serve as a collaborative platform, bringing together different stakeholders, such as architects, conservators, and local authorities, to work on heritage preservation [41].

Additionally, the collaborative workflow in an HBIM project for the restoration and conservation of cultural heritage highlights the importance of interdisciplinary cooperation and the potential for HBIM to facilitate complex heritage conservation efforts. This approach emphasizes the role of HBIM in fostering communication and collaboration among various experts, including historians, engineers, and conservationists. The project demonstrated how HBIM can be used to integrate diverse types of data, such as historical records, structural analyses, and material studies, into a single coherent model. This integration enables a more comprehensive understanding of heritage buildings and supports informed decision-making in conservation practices. The collaborative nature of HBIM projects also ensures that all relevant perspectives are considered, leading to more holistic and sustainable conservation outcomes [42].

3. Scan to Heritage BIM (The Method)

The use of 3D reality capture methods in legacy documentation will be examined in this scientific study, with an emphasis on the advantages and potential advancements in this field. Ghiza Market will be used as a case study where these methods have been effectively used to record and preserve historical sites, emphasizing how they affect conservation efforts and public involvement. The method used in this study (as shown in Figure 4) to provide a 3D model and digital database utilized by HBIM into the case study of Ghiza market has three main steps: data collection, data processing, and 3D HBIM. In this study, the data collection is separated into first the physical and visual site visit, which also includes the preparation for data collection as well as the site analysis. Secondly is the data collected for the site by 3D reality capture, which uses different 3D scanning techniques: TLS and aerial photogrammetry. Furthermore, Cyclone 360, Pix4DCloud, and Agisoft metashape v.2023 are employed in photogrammetry to process data and generate 3D models from captured photographs. These software solutions integrate historical data, including images, sketches, and written documents, into the models to enhance their informational value. This approach transforms HBIM into a preservation and interpretation process for heritage assets. It goes beyond creating digital representations by contextualizing architectural features within their historical and cultural significance, ensuring their legacy for future generations.

3.1. Site Investigation

The Ghiza market is located on the Sultani road between Makkah Al Mukarramah and Medina, 4 kilometres from the village of Badr, about 30 meters from Medina (Figure 5). Through site survey and analysis, the area of the market was estimated 35,100 m² (270 m × 130 m). Ghiza Village, like many other historical sites in Saudi Arabia, requires documentation in order to be preserved. There is no digital documentation to help conserve historic buildings, no credible reference data for the restoration process, and no digital data to allow remote viewing of the village. Moreover, 51 of Ghiza village buildings are in fair condition, 36 buildings are in bad condition, while 17 are in good condition (Figure 6). This was based on the initial assessment, which included a number of criteria. These criteria include visual inspections and basic assessments of structural integrity, material condition, and environmental impacts.

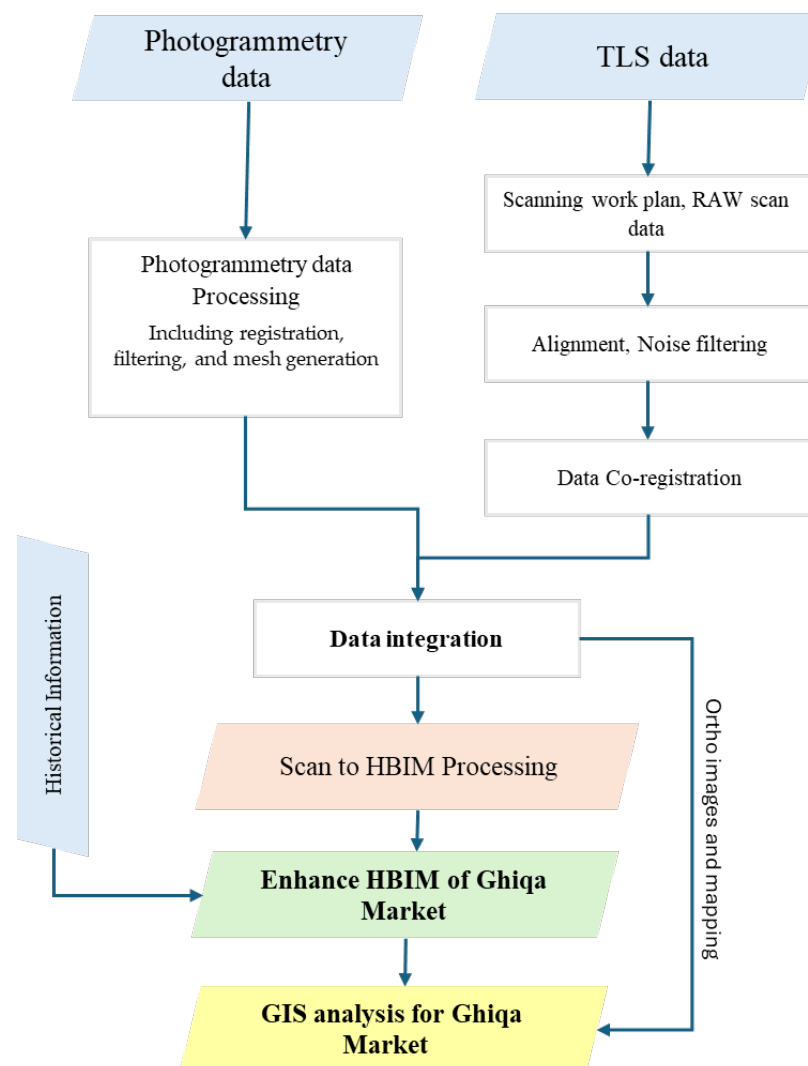


Figure 4. The workflow of HBIM for Ghiqa market.

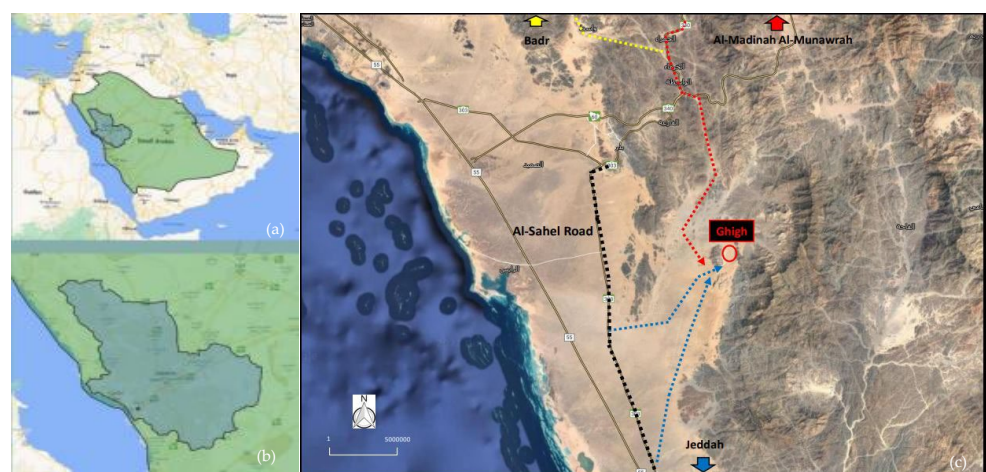


Figure 5. Geographical maps of: (a) Kingdom of Saudi Arabia, (b) Al-Madina province, and (c) site of Ghiqa market.

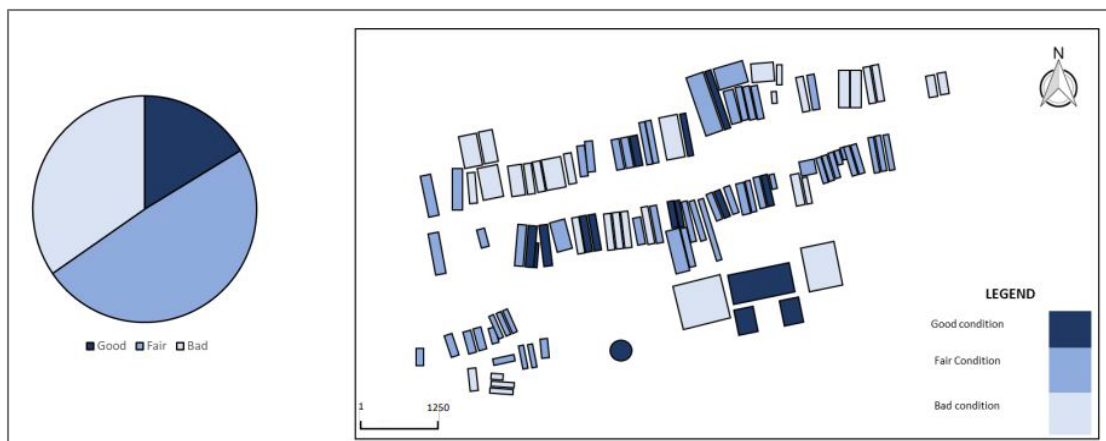


Figure 6. Ghigh village building condition.

The height of the store buildings is 2.80 m, 3 m for the mosque, while the palace is the highest with 4.5 m (Figure 7). The palace has the biggest space area of the other buildings, while the stores have the smallest (Figure 8).



Figure 7. Ghika buildings: (a) The palace, (b) The Mosque of Ghika, and (c) The stores.

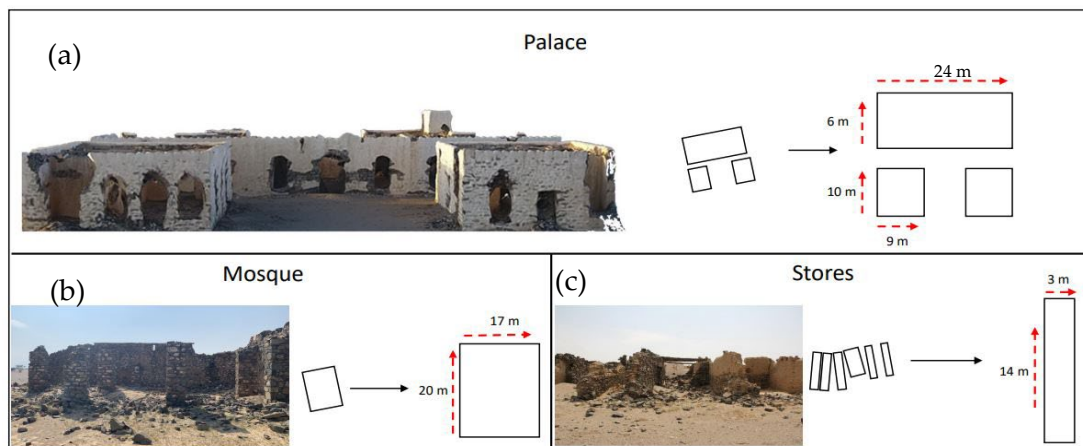


Figure 8. Ghika village buildings dimensions: (a) The dimensions of the Palace, (b) The dimensions of the Mosque, and (c) The dimensions of the stores.

The architectural observations of the market show the different materials that are used in Ghigh village buildings such as rocks, wood, clay, and palm branches (Figure 9). A store in the market is divided into two parts: a section for displaying goods and the back for storing. Also, there are 3 drainage holes in the side of the mosque courtyard that can be seen. Moreover, the size ratio of the windows and doors of the palace compared to its walls is notable (Figure 10).



Figure 9. Architectural documentation of Ghiqa village: (a) Shows different building materials in the store, (b) room in the palace, (c) the paths in the palace, (d) store in Ghiqa market, (e) room in the palace, and (f) store in the market.



Figure 10. The palace in Ghiqa village: (a) shows window and door size ratio to wall, (b) shows window to wall ratio.

3.2. Aerial and Close-Range Photogrammetry

The image survey of the historic Ghaiqa Market, aimed at capturing its unique architectural features, spanned two weeks: one for capturing images using a Canon EOS 60D camera and another using drones. The Canon EOS 60D utilized a CMOS sensor with a sensor size of 22.3×14.9 mm (APS-C format), capturing images at a resolution of 5184×3456 pixels. The maximum resolution is 5184×3456 pixels ($4.3 \mu\text{m}$ pixel size) and (18.1 effective megapixels). In addition, the film speed is 100–6400 (expandable to H: 12,800). Figure 11 shows the use of close-range photogrammetry in Ghiqa Market.



Figure 11. Using close-range photogrammetry (CRP) for historic Ghaiqa market.

For aerial photogrammetry, the DJI PHANTOM 4 was used (Figure 12), with entry-level professional drone and powerful obstacle avoidance. The weight with the battery and propellers included is 1388 g. The maximum flight time is approximately 30 minutes with forward, backward, and downward Vision Systems. The camera sensor is 1" CMOS with 20 M" effective pixels and a maximum video recording resolution of 4K 60P. Some of the drone photos before integrating them with the laser scanning data are seen in Figures 13 and 14.



Figure 12. The process of aerial surveying: (a) DJI Phantom 4, and (b) Pix4D capture.



Figure 13. Aerial survey outcomes: (a) Shows the Palace from the top via Drone, (b) shows Ghiqa Historical Village via Drone.



Figure 14. Ghiqa historical village via PIX4D.

3.3. 3D Laser Scanning Phase

Terrestrial laser scanning (TLS) was implemented in order to scan the facades of Ghiqa's market from the exterior to the interior (Figure 15 shows the use of Leica RTC

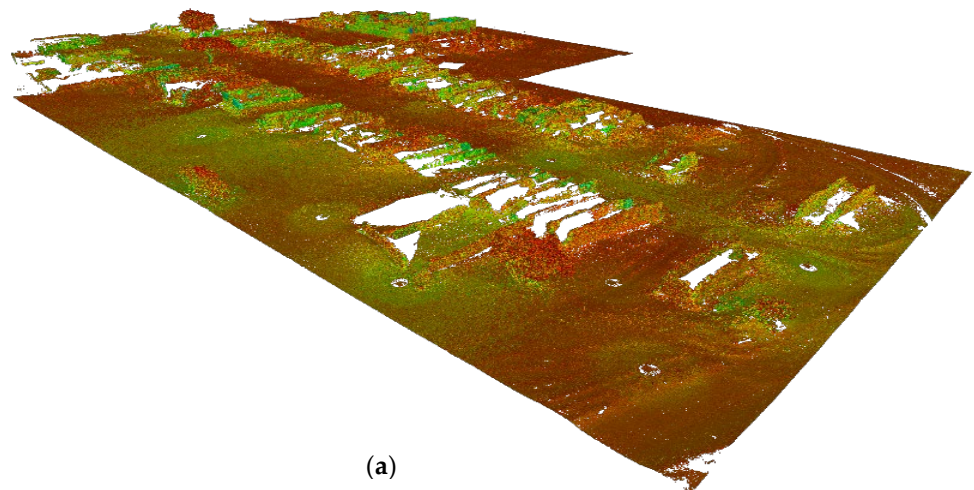
360 laser scanner). This process spanned approximately 7 working days and resulted in a comprehensive 3D point cloud representation of the entire building. Subsequent processing of the 3D point cloud data required approximately 3 weeks. The operation commenced with the precise positioning of scan stations using a Leica total station, employing a back-sight approach to establish coordinates for these locations. This method generated precise points both inside and outside Ghiqa's market, thereby creating a detailed coordinate map for each scanned position. After site visit analysis, there were 55 stations selected (Figure 16) depending on the coverage of all the areas; there should be overlapping between them. The selection of stations depended on visibility of the site and overlapping. The data collection utilized the Leica RTC360 equipped with a Visual Inertial System (VIS) for laser scanning. Laser scanning, a widely adopted method in land surveying, excels in accurate measurement and data collection from various objects, surfaces, buildings, and landscapes. It captures data in the form of point clouds, comprising millions of 3D coordinates (x , y , and z) (see Figures 17 and 18). The Leica RTC360 represents a cutting-edge 3D reality capture solution that allows users to document and capture their built environments in 3D. Its capabilities enhance efficiency and productivity both in the fieldwork and in the office work, offering fast, user-friendly, accurate, and portable hardware and software solutions. VIS is a sensor fusion technology that combines data from both visual and inertial sensors to estimate the position, orientation, and motion. The initial step involves integrating the registered point cloud data into Leica Cyclone (for TLS applications) and employing heuristic methods to segment the point cloud into distinct building components, facilitating detailed sector analysis. Subsequently, the TLS point sets are imported into Recap for data cleaning and refinement. Additionally, in this project, measurements are derived from aerial images captured by drones, which are processed to transform 2D images into precise 3D models. This process involves depth perception through the amalgamation, correction, and presentation of imagery, enabling users to visualize and measure objects in three dimensions with accuracy (Figure 19).



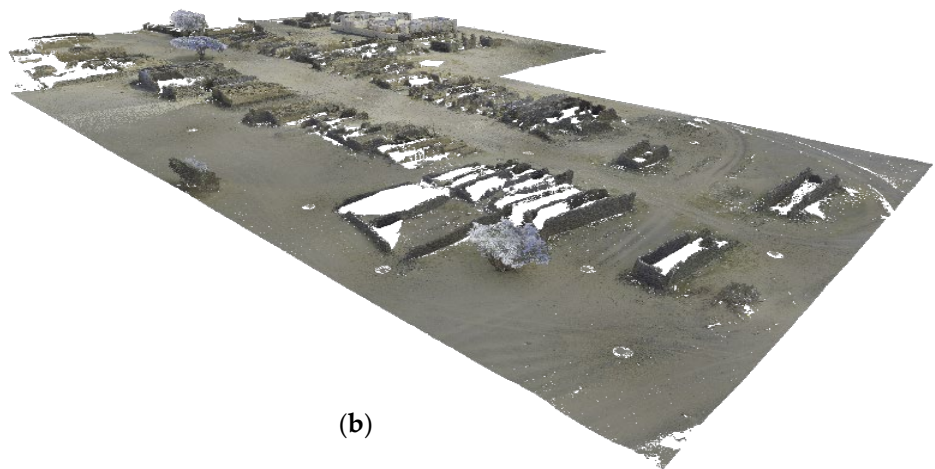
Figure 15. Using 3D laser scanning.



Figure 16. The 3D laser scanning station locations on the site.



(a)



(b)

Figure 17. Different formats for the point cloud data of Ghika's Market site: (a) intensity format, and (b) RGB format.

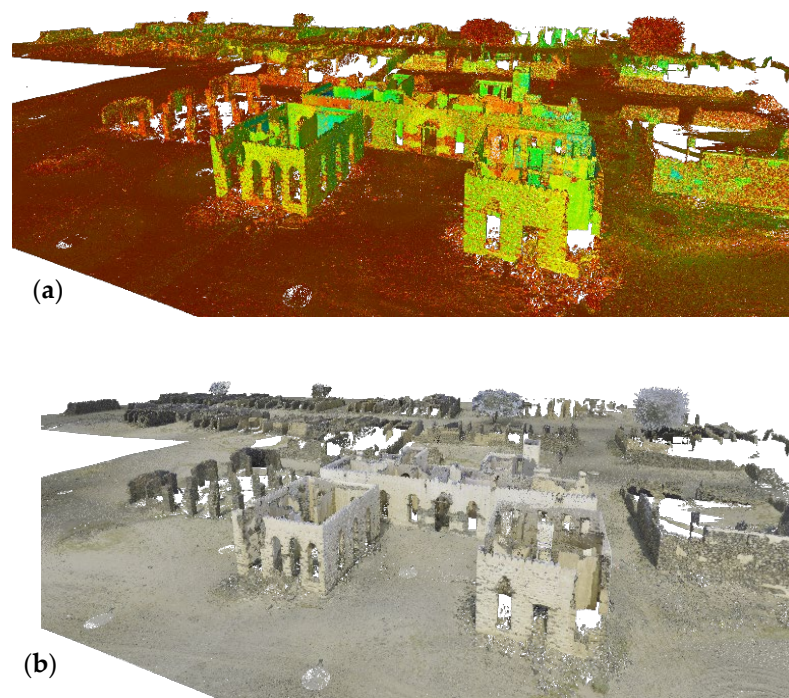


Figure 18. Different formats for the point cloud data of Ghiqa's Palace: (a) intensity format and, (b) RGB format.



Figure 19. Different shots for laser scanning shows: (a) the Ghiqa's market palace from the back, (b) Shows the Ghiqa's market palace from the left side.

3.4. The Integration of the Laser Scanning and Photogrammetry Point Cloud Data

The project concluded with the integration of laser scanner and drone data using different software to export the data in a suitable format to be integrated into one complete 3D point cloud model. This involved aligning photos, normal detail, and texturing the model. The laser data of the stores and the palace were linked with the drone data, resulting in the final output. Additionally, a Digital Elevation Model (DEM) was created to provide a detailed representation of the terrain and topography surrounding the Ghiqa Historical Market. This comprehensive approach ensured that both the architectural and geographical aspects of the site were accurately documented, contributing to a holistic understanding of the heritage site (Figures 20 and 21).

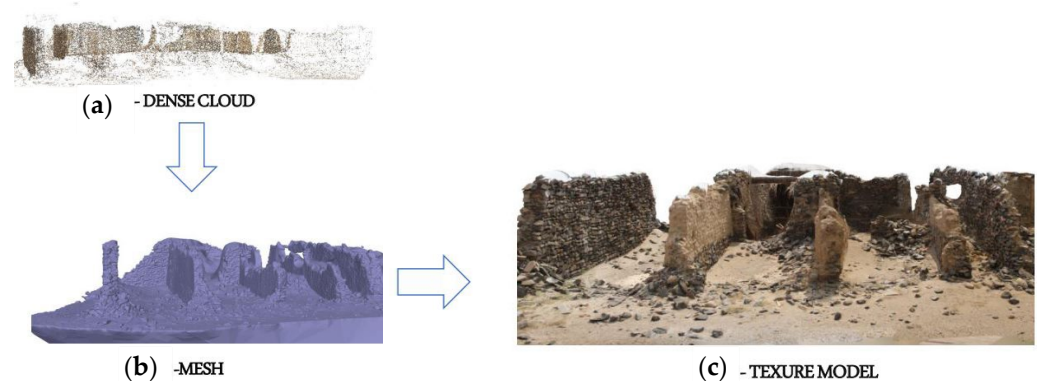


Figure 20. Close-range for the building result process started from: (a) Dense cloud, (b) Mesh, and (c) Texture model.

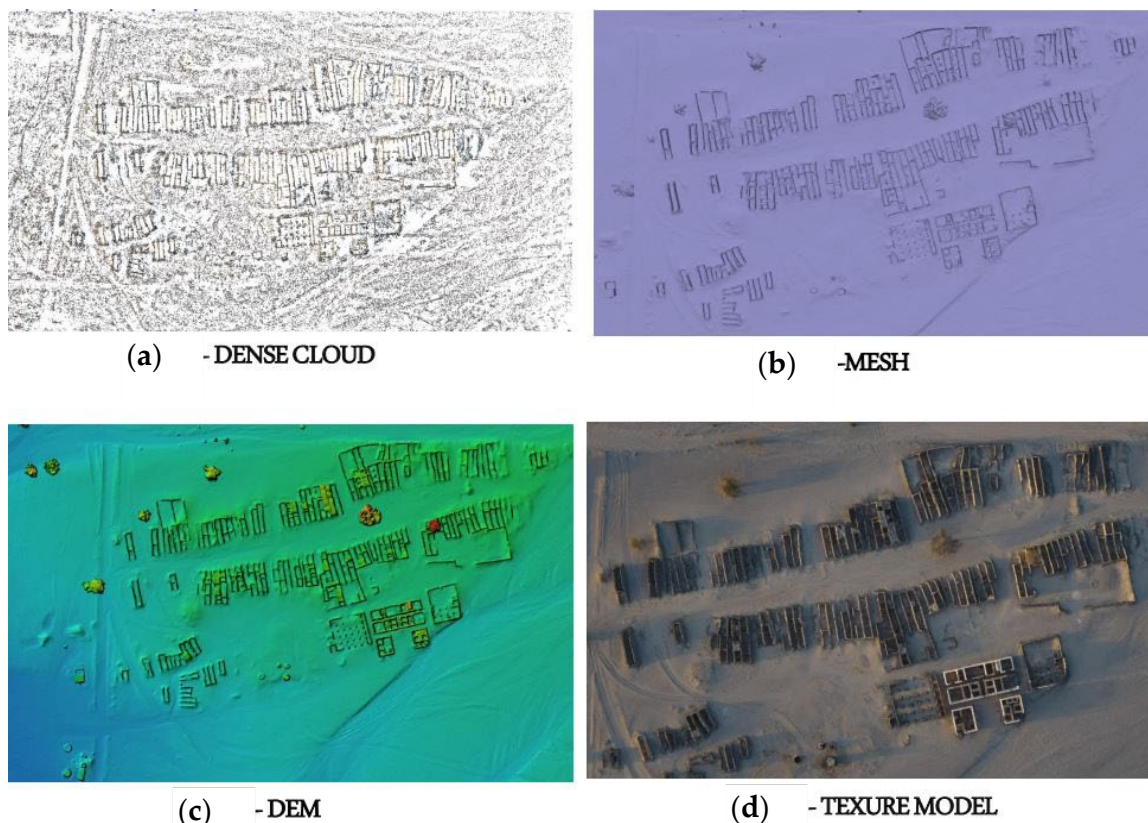


Figure 21. Drone (Agisoft Metashape) result process for the site started from: (a) Dense cloud, (b) Mesh, (c) Digital Elevation Model (DEM), (d) Texture model.

3.5. The Heritage BIM of Ghiqa Historical Market

The method used in the implementation of Heritage Building Information Modelling (HBIM) for the recording and conservation of the Ghiqa Historical Market involves several methodological procedures. First, a thorough evaluation of the market's cultural significance is conducted to identify heritage value. Subsequently, advanced data collection approaches, for instance, photogrammetry and 3D laser scanning, are utilized to thoroughly record the market's historical background and architectural features. HBIM software processes and integrates this data to produce a comprehensive digital model of the market that includes contextual information, historical archives, and point cloud data [29]. The resultant HBIM is a comprehensive tool for structural evaluations, spatial analysis, and well-informed decision-making about conservation and restoration initiatives. The approach encourages stakeholder engagement and interdisciplinary collaboration to enable community participation in heritage conservation. By using this method, the Ghiqa Historical Market is recognized as a representation of Saudi Arabia's rich cultural legacy and is digitally conserved. Before modelling the structure with BIM software, it's important to undertake point cloud techniques including noise reduction, removing erroneous points, and removing unnecessary scene pieces. TLS results were then integrated into the BIM stage. In this stage, Autodesk Revit version 2024 and the HBIM method were used. Additionally, the 3D orthographic images were inserted in their correct location for façade elevations, plans, sections, and ground points (Figure 22). Furthermore, the primary phase involved the building's walls based on the plan data. Illustrations were provided for all building elements, including doors and windows. Prior to modelling the data into the survey, TLS data were used to measure library parameters and apply them to specific areas of the library. The eBIM plugin adds this feature to complete the building model and then compare between laser scanner and Revit (Figures 23 and 24).

Moreover, to integrate historical data information (text) into the BIM model in Revit, the following methodology is employed. Initially, historical data, including archival documents, descriptive narratives, and other textual information, are digitized and systematically organized. This digitized information is then imported into the Revit environment as text annotations linked to specific architectural elements such as walls, windows, and doors. Revit's text annotation tools facilitate the placement of these notes directly within the model, thereby embedding historical context into the BIM. The process involves creating callouts, which are detailed view references that highlight specific parts of the model and incorporate the text annotations. These callouts serve to enhance the clarity and contextual understanding of the historical data within the model (Figures 25 and 26). To export the annotated model as a PDF file, Revit's sheet creation feature is utilized. Sheets are designed to include all relevant views, sections, and callouts, thereby compiling a comprehensive representation of both visual and textual historical information. The "Print" or "Export" functions in Revit are then used to generate PDF files from these sheets, ensuring that the integrated historical data and annotations are preserved in a portable document format.

This methodology not only enhances the documentation and presentation of historical information within the BIM model but also ensures that the heritage value is comprehensively recorded and accessible. By facilitating the export of annotated models as PDF files, the approach supports the dissemination and communication of heritage data among stakeholders, thereby contributing to informed decision-making in conservation and restoration initiatives. The final output from the HBIM process included 3D rendered shots of the Ghiqa Historical Market, providing visually detailed representations that further aid in preservation and educational efforts (Figures 27–29).

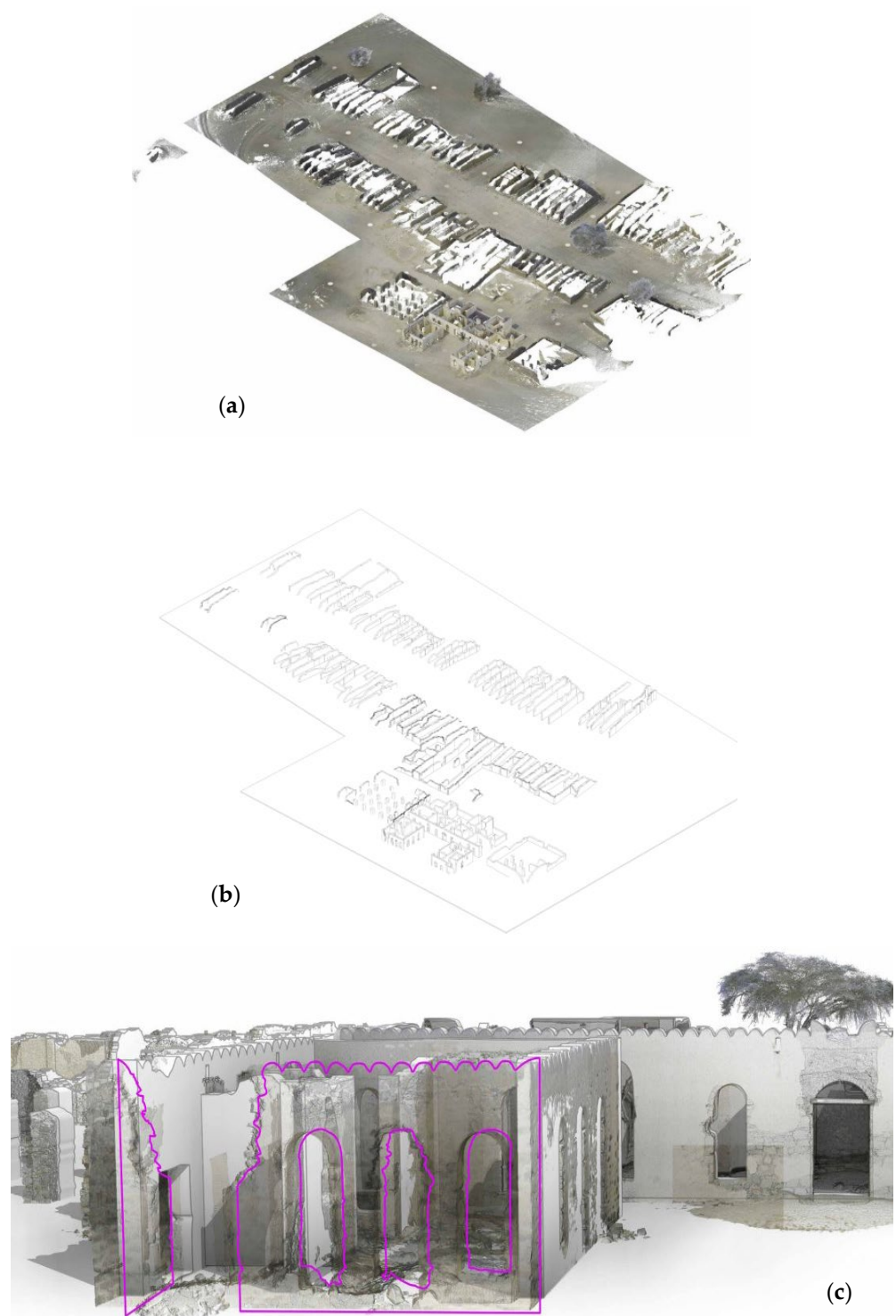


Figure 22. 3D laser scanner to Heritage BIM process: (a) Shows the laser scanning outcome of the site, (b) Shows the Revit modelling of the site, and (c) Scan to Heritage BIM modelling.

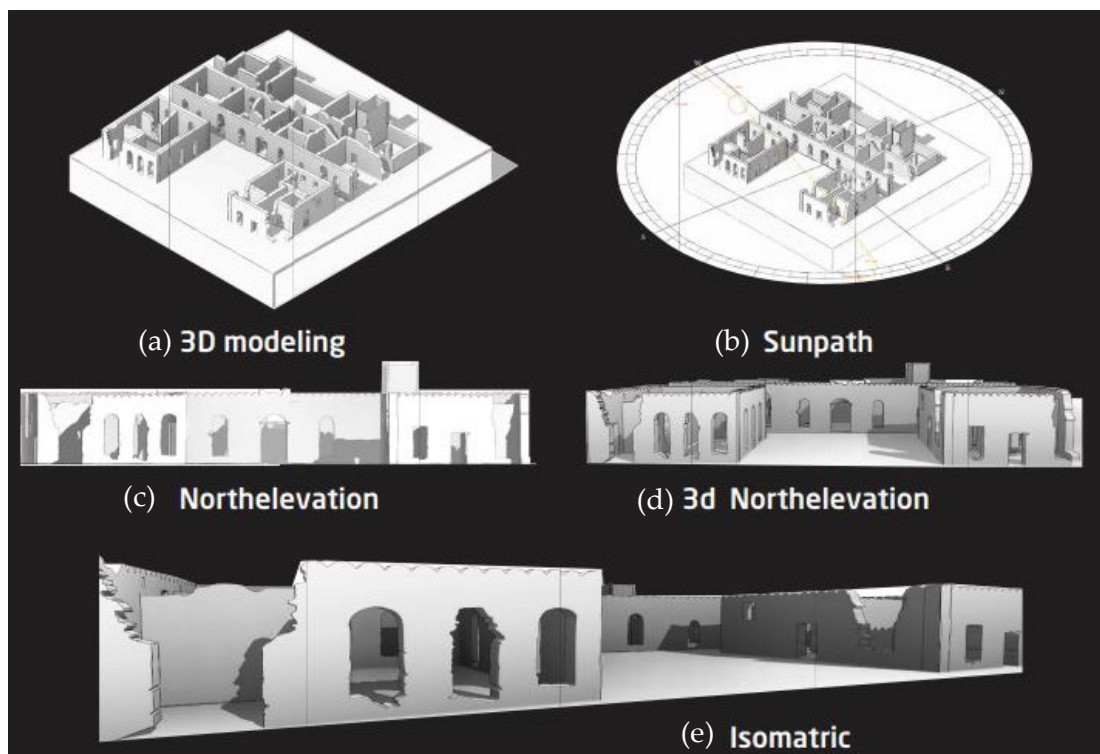


Figure 23. Revit modelling result: (a) 3D Isometric modelling, (b) Sun path, (c) North elevation, (d) 3D north elevation, and (e) Isometric of the north elevation.

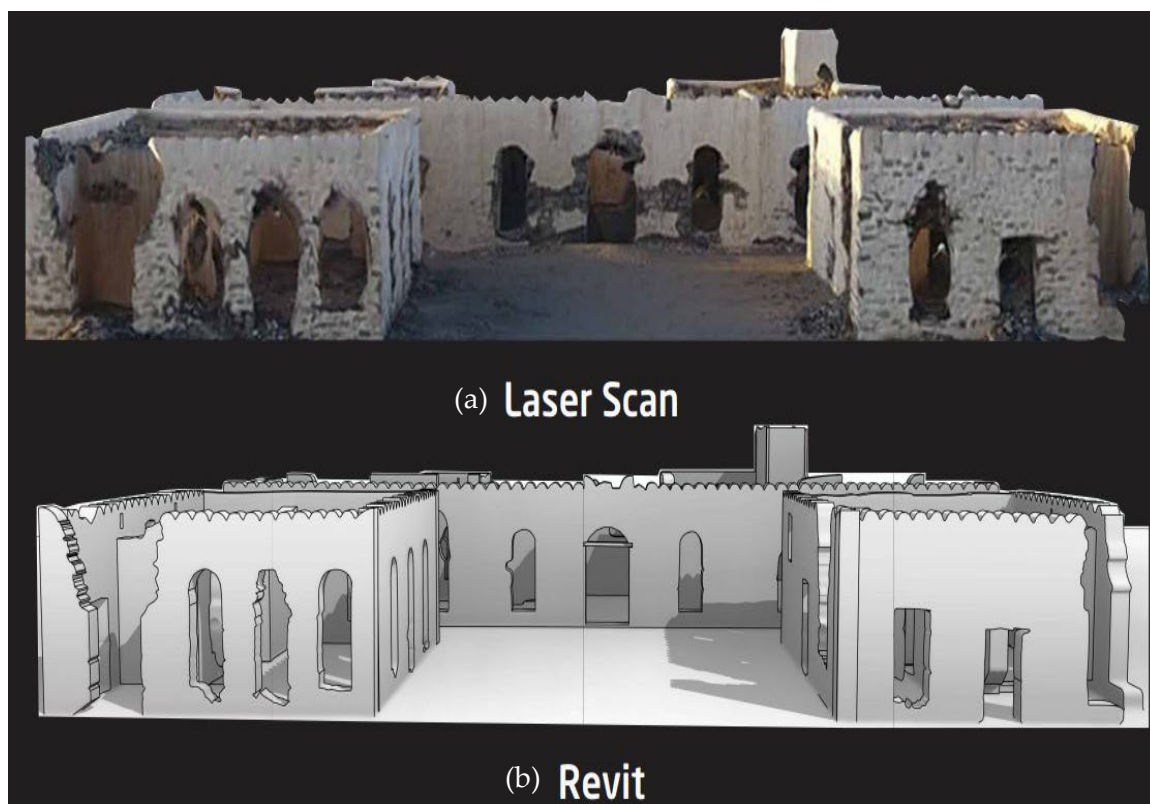


Figure 24. Comparing between the palace out come in: (a) Laser scanning format, and (b) Revit format.

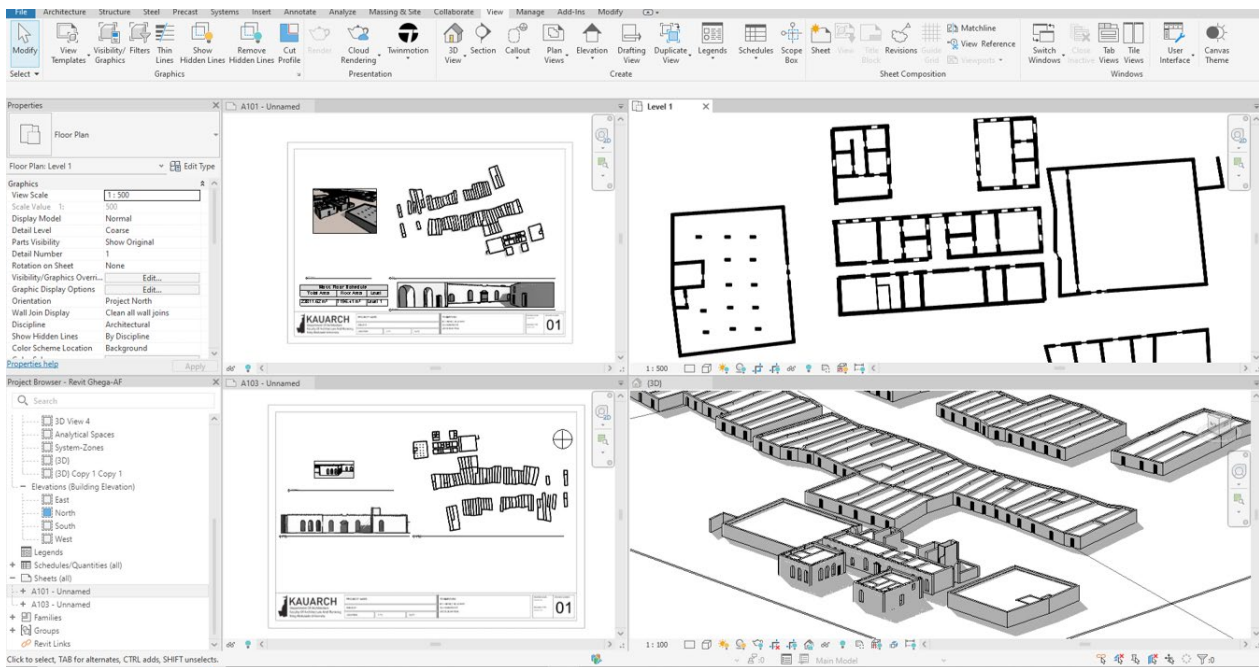


Figure 25. Import scanning data and images to create BIM models and trace architectural elements of the Ghiqa Historical Market.

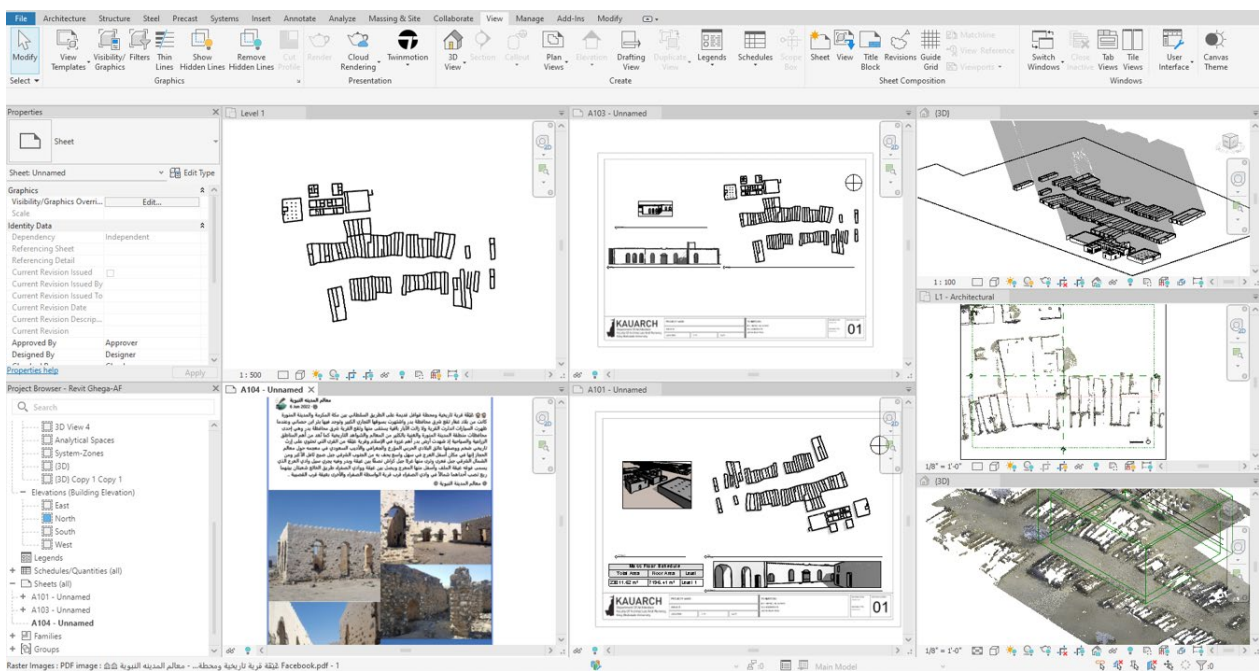


Figure 26. Import scanning data and images and historical data to create BIM models and trace architectural elements of the Ghiqa Historical Market.



Figure 27. 3D HBIM modelling of the Ghiqa Historical Market.



Figure 28. The Ghiqa Historical Market HBIM model after adding texture.



Figure 29. The Ghiqa place HBIM model after adding texture.

3.6. Geospatial Analysis

The Ghiqa Historical Market undergoes comprehensive geospatial analysis using 3D laser scanning and photogrammetry techniques, facilitated by GIS software. Point cloud data and high-resolution images capture the market's intricate architectural elements and spatial characteristics with unprecedented accuracy. The 3D laser scanning procedure precisely measures the market's physical structure, while photogrammetry enhances visualization with detailed textured representations. These datasets are seamlessly integrated into ArcGIS pro software to enable spatial analysis of the market's layout, structural integrity, and historical relevance.

Integrating datasets from 3D laser scanning and photogrammetry into GIS software begins with capturing precise XYZ coordinates of the Ghiqa Historical Market's structure through laser scanning and creating textured 3D models from high-resolution images. After processing to align and register the data, it is imported into GIS platforms like ArcGIS pro or QGIS. This integration facilitates spatial analysis, including assessing the market's layout, overlaying GIS layers to evaluate structural integrity, and analysing historical changes in architecture and land use. Visualization tools within GIS aid in presenting findings for informed decision-making in conservation, urban planning, and historical preservation efforts.

Geospatial analysis techniques such as spatial interpolation, proximity analysis, and overlay analysis (Figure 30) are employed to detect spatial patterns, identify potential threats, and assess the cultural heritage value of the market in relation to its surroundings. These analyses can be used as “proof of concept”, and more advanced analysis will be in the future work of this project. The total area of the market is 35,100 square meters, with 10,500 square meters of solid areas and 24,600 square meters of void areas (Figure 31). By leveraging new data-capturing methods and GIS technology, researchers and conservationists gain valuable insights into the spatial dynamics of the Ghiqa Historical Market, enhancing preservation and management decisions. This interdisciplinary approach fosters collaboration among architects, historians, archaeologists, and urban planners, contributing to the protection of Saudi Arabia's architectural heritage.

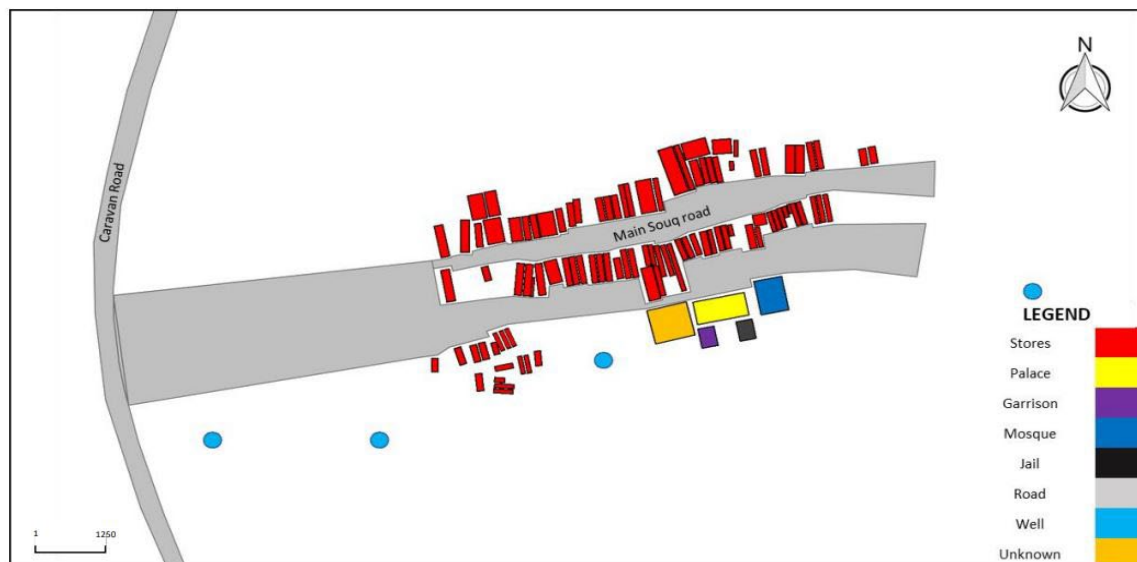


Figure 30. Ghigh village Land Use Master Plan.



Figure 31. Spatial Analysis of Ghiqa Historical Market. The pie chart shows that 65% of the total area is void (24,600 m²), while 35% is solid (10,500 m²).

4. Discussion

In this section, the detailed findings of the study are presented, including the development and analysis of 3D BIM models, structural assessments, and condition classifications of the buildings in the Ghiqa Historical Market. The integration of historical data and its implications for preservation and restoration planning are also discussed. Using point cloud data from 3D laser scanning, detailed digital models of the Ghiqa Historical Market were created. These models accurately capture the architectural features, structural systems, and material attributes of the buildings. The accuracy of these models was validated against manual measurements and historical records, ensuring a high level of precision. The 3D BIM models were utilized to conduct comprehensive structural analyses. Structural loads and stress distributions were simulated to identify potential weaknesses and areas requiring reinforcement. For example, the stress distribution maps derived from the analyses indicated high-stress regions that may be susceptible to structural failure, highlighting critical areas needing immediate attention to prevent further deterioration.

A condition assessment of the buildings was performed, classifying them into “fair”, “bad”, and “good” categories based on preliminary criteria including structural integrity, material condition, and environmental exposure. The detailed visual and structural data provided by the 3D models supported this classification. The assessment found that 51 buildings were in fair condition, 36 in bad condition, and 17 in good condition. Examples of buildings in each condition category were documented with corresponding 3D model snapshots, providing visual evidence to support the findings.

Furthermore, historical archives and photographs were integrated into the 3D models to enrich the contextual information. This integration added a comprehensive historical narrative, illustrating changes over time and the original state of the structures. The enriched models provided a holistic understanding of the Ghiqa Historical Market, aiding accurate preservation and restoration decisions.

The results of the study demonstrate that HBIM significantly enhances the accuracy and efficiency of architectural documentation. The detailed digital models not only support condition assessments but also facilitate interdisciplinary collaboration and knowledge transfer. By including the Ghiqa Historical Market in the UNESCO World Heritage List, international attention and resources for its preservation can be attracted. This designation would underscore the market’s cultural and historical importance, fostering a sense of pride and responsibility in its maintenance.

5. The Conclusions and Final Remarks

This study has demonstrated the significant potential of integrating HBIM with GIS databases to enhance the documentation and preservation of cultural heritage sites, as evidenced by the case study of the Ghiqa Historical Market in Saudi Arabia. By leveraging advanced digital technologies such as 3D laser scanning and photogrammetry in conjunction with traditional architectural documentation methods, a comprehensive and detailed digital representation of the market was created. This model not only captures intricate architectural details but also incorporates contextual information, thereby enhancing the historical value and authenticity of the site. The integration of these methodologies allows for more informed decision-making regarding preservation and restoration activities, ensuring the protection of Saudi Arabia's rich cultural heritage for future generations. The interdisciplinary collaboration and stakeholder engagement highlighted in this study underscores the importance of a holistic approach to heritage preservation. Furthermore, by adhering to UNESCO's preservation guidelines, this research supports the nomination process for the UNESCO World Heritage List, thereby strengthening the recognition and safeguarding of cultural heritage sites worldwide. Looking forward, the methodologies and insights gained from this research offer a valuable framework for similar preservation efforts globally. By fostering the long-term preservation of our shared cultural heritage, this study contributes to the broader discourse on heritage conservation, providing a robust foundation for future initiatives.

Funding: This research work was funded by Institutional Fund Projects under Grant No. GPIIP: 264-137-2024 provided by the Ministry of Education and King Abdulaziz University, DSR, Jeddah, Saudi Arabia.

Data Availability Statement: Data is unavailable due to privacy.

Acknowledgments: The author would like to express sincere gratitude to Eng. Abdullah Alhibshi and Eng. Ammar Adas for their invaluable support during the fieldwork. Special thanks are also extended to Eng. Rania Alali for her essential support throughout the project. The authors gratefully acknowledge the technical and financial support provided by the Ministry of Education and King Abdulaziz University, DSR, Jeddah, Saudi Arabia.

Conflicts of Interest: The author declares no conflict of interest.

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