buildings

Article

Conservation of Socio-Religious Historic Buildings: A Case Study of Shah Yousuf Gardez Shrine

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Abstract: Historic buildings are considered assets for generations. The use of 3D interactive models is an excellent way to document such historic cultural heritage. Such buildings include socio-religious buildings, such as shrines and religious monuments. Digital technologies such as photogrammetry and laser scanning play a pivotal role in monitoring and safeguarding precious shrine cultural heritage. These advanced techniques allow the capture of details and accurate 3D representations of cultural artifacts, architectural structures, and even entire shrines. This study deals with research related to the conservation of the selected historic shrine of Shah Yousaf Gardez. A laser scanner methodology was used to produce a high-level detail interactive model translated into a heritage building information modeling (HBIM) prototype. This HBIM model has been designed to maintain the historical details of the shrine, especially geometric features, artwork present on the surface, and condition of structural as well as non-structural components. Data analysis of defects in structural and non-structural components was also analyzed in the study. This study was conducted fort the first time for a shrine case study. It will not only help to document and preserve historic buildings and cultural heritage but also monitor potential degradation or damage over time. Using this technology, scheduled conservation and restoration efforts ensuring the long-term preservation of these invaluable treasures can be adopted.

Keywords: sustainability; heritage; digital survey; scan-HBIM; conservation

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1. Introduction

Historic buildings and heritage sites represent the identity, culture, architecture, and lifestyle of people belonging to a certain time, and their availability for the next generations is a glorious treasure. Cultural heritage can be classified into two parts; tangible heritage, which has a physical dimension and includes a variety of historical works and buildings, and intangible heritage, which includes the creators of artistic, scientific, and other works, such as artists and elites. The protection and maintenance of such heritage work plays a significant role in the registration of the national identity of the community and also serves as an important element of its economy [1]. Technology has become an important part of the built heritage in its various forms and the evolution of such technologies developed various modeling tools, such as building information modeling (BIM). It provides a digital presentation of the physical and functional characteristics of a building. The conservation of historic buildings depends on a series of activities, such as inspection, surveying, drafting, modeling, and post-construction management. In contrast to traditional methods, new digital documentation techniques have gained attention among scholars and professionals [2]. Historic building information modeling (HBIM) and its applications have revolutionized the fields of architecture, engineering, and conservation. Indeed, the implementation of this advanced technique is useful in the cultural asset preservation process. H-BIM changes the capability of transmitting information during the overall life cycle of a historic structure. The emergence of such collaborative digital workspaces has a major impact on specific promising occupations like BIM managers and 3D surveyors to create some valuable and advanced skills of information technology (IT) to solve various problems in the workplace. These aspects are encouraging to reorganize the different fields relevant to the preservation, restoration, and conservation of the historic built environment. HBIM technology harmonizes international legislation and efforts in preserving, restoring, and rehabilitating significant historic and modest vernacular buildings [3]. Burra Charter of ICOMOS stated that conservation "includes all the processes of looking after a place to retain its cultural significance (CS) which encompasses the activities that are aimed at the safeguarding of a cultural resource so as it retains its historic value and extend its physical life" [4]. The Shrine of Shah Yousuf Gardez is located about 600 m southwest of the old fort of Multan. This historic site is a small rectangular building with a flat roof. The shrine is decorated with blue and white glazed kashi tiles embellished with floral and geometric patterns and aina-kari (mirror work) on the interior. The wooden roof is embellished with work known as sozan kari.

Previously, heritage documentation of historic buildings using various tools and methods has been developed to analyze and manage the data collected by structural health monitoring systems. These methods include the use of BIM and the visualization of data using virtual reality and augmented reality [5–8]. The integration of BIM with other techniques has shown the potential to create a more accurate and comprehensive view of SHM data [9]. This technology can be used in various monitoring applications, such as asset management and energy efficiency. For this purpose, BIM in combination with other techniques has been applied to existing structures, like lighthouses [10]; the Palace of Monserrates [11]; Villa Klonaridi, Greece [12]; and UNESCO World Heritage Kinderdijk-Elshout in the Netherlands [13]. It likely discusses the methods and technologies employed to gather data for the BIM modeling of the monastery Engine House Paços Reais in Lisbon [14], the Gothic Monastery of Batalha in Portugal [15] Huadong Hospital, China [16]. A platform that is based on BIM has been developed to protect heritage timber structures [17]. These focuses on a BIM-based cultural heritage asset management tool, which likely discusses the application of building information modeling (BIM) in managing and preserving historic buildings, including the Gothic Monastery of Batalha in Portugal, which focuses on data acquisition in cultural heritage buildings using non-destructive techniques, with a specific case study of the Gothic Monastery of Batalha in Portugal. It combines a multi-dimensional model with information from multiple sources to provide more effective and convenient protection and uses SHM systems [18] and IoT-based BIM solutions for real-time monitoring of historic structures [11]. The framework for BIM was developed to allow the users to perform various functions, such as analyzing and managing the structural condition of the building [19]. A terrestrial laser scanner was also utilized to obtain precise data [20]. This technique was also used in combination with other techniques [21].

BIM has been studied to enhance the use of historical buildings in the cultural heritage sector. This paradigm allows for the creation of 3D models that are based on various collected information sources [22]. The use of BIM allows for the continuous monitoring of buildings' response and condition [23,24]. Using 3D laser scanning and BIM together can help enhance the process of preserving heritage buildings. Numerous initiatives are being carried out in Egypt to integrate these technologies in the restoration and documentation of heritage structures [25]. The case study was conducted to evaluate the usability and feasibility of a fusion method that combines BIM and real-world 3D models for the development of a digital twin of a historical building in China. The study focused on the use of SHM2 to improve the performance of the building's structural systems. This method aims to provide a comprehensive view of the condition of the building's structural components [26,27]. Civil engineering projects have numerous complex tasks, such as damage assessment and structural health monitoring. The strength and health of structures are affected by different factors, such as transportation, the materials production stage, placement, and labor [28]. Due to the technological advancements that have occurred in the field of structural health monitoring (SHM) [29], the use of wireless sensors has increased. This method is now commonly used to monitor the condition of the building's structural components. The increasing number of sensors and the Internet of Things can be used to improve the efficiency of the building information modeling process [30]. BIM-based visual warning systems have been integrated with LSTM Network's structural health monitoring platform [31]. Remote sensing, HBIM, and SHM were also utilized to keep track of historic structures [32].

Three-dimensional models are created, and material information is added using HBIM methodology [33]. Models are developed using BIM, and data are collected using a laser scanner, especially of damaged parts of the structures [34]. Currently, the BIM technique combines 3D modeling and information management for data management of heritage buildings [35]. In recent years, using BIM, a sample structure of Wang Temple in Karpacz, Poland has been digitally accurate spatial documentation [36]. Similarly, a traditional village—Hexinwu, China—has been documented using the integration of UVA images and point clouds from laser scanning [37]. BIM, along with Auto Desk Revit 2020 and Auto Desk Insight 360, has been utilized to save energy projects for the holiest Theotokos [38]. A similar technique was utilized for the preservation of Khan Hamu Quddo (Mosul) [39]. In recent years, BIM has been utilized for the conservation of the Basilica of Colle Maggio and the Arch of Peace in Milan Italy) [40]. Even it has been utilized for the sustainable retrofitting of heritage buildings in Egypt [41]. It was also used to investigate the relationship between Survey, HBIM, and 3D models for the brick Renaissance domes in Campania [42]. Even complex geometries like The Engine House Paços Reais in Lisbon was documented through 3D scanning and HBIM [14]. This evolution led towards the digital twin (DT) concept and was tested for the Santiago church in Jerez de la Frontera (Spain) [43].

The entire Seoikheon Building of Jeonju Pungpajigwan (Korea) was studied using HBIM model [44]. 3D MIB modeling was also done using LiDAR and UAV surveys [45]. In the UK, HBIM was utilized to combine tangible and intangible data which was used for asset lifecycle management [46]. Even for time played historical data for historic palaces in Croatia [47]. That is why it is presumed that HBIM will substitute the traditional survey procedures [48]. Because it can manage diverse datasets, and explore practical applications in both BIM and GIS realms [49]. Two-stage ontology-based methodology was tested in a BIM environment on the city walls of San Ginesio (Macerata, Italy), which enhanced the management of built heritage [50]. Similarly, it was applied to the Greco-Roman Museum at Alexandria, in Egypt [51] and Villa Castel Nuovo in Palermo (Italy), considering external façade decay heritage documentation [52].

The availability of a BIM environment can help in the development of more complex diagnostic procedures for heritage maintenance and monitoring. This is because the information collected through the H-BIM can be used to improve the understanding of the building's evolution [53,54]. By integrating point cloud processing and photogrammetry technologies, historic structures can be monitored and maintained with a digital twin framework that can be used for asset management. This method utilizes a virtual model of the structure created by taking into account different inspection times. Unfortunately, there is a lack of effective integration between the data collected by H-BIM and other datasets [55]. A building information modeling (BIM) approach is proposed that takes advantage of the data collected by monitoring systems. The real aim of the research is to develop a digital & sustainable framework of conservation in the South Punjab region more specific for the shrine but also applicable to other heritage builds and sites. It is an academic research work that is highly beneficial to the relevant authorities like the Directorate General of Archaeology, Archaeology & Museums Departments, the Auqaf & Religious Affairs Department, and Walled City Authority. As these departments deal with the preservation and Conservation work of heritage assets in South Punjab. It is the main intention that this research must be used by the authorities to manage the conservation/restoration of the building. All authorities mentioned above would be the potential users of this research.

This will ultimately facilitate the common people as visitors of such heritage sites and buildings to promote them and save them.

This method can generate parametric models of the structures and allow for dynamic and interactive visualizations [56]. Also structural engineering [57]. This method can visualize key structural parameters and provide long-term management of data. It can also facilitate data exchange by creating industry foundation class (IFC) compliant models. Although it is exciting to see the adoption of BIM in the management of heritage buildings, it is not without its challenges [58]. To maximize the efficiency of heritage buildings, the use of H-BIM should be identified and its various challenges overcome. For instance, in Italy, a study conducted on the structural modeling of a palace in Sabbioneta revealed that the method could help improve the management of the town's historic buildings [59]. The emergence of BIM as a repository and data management tool has led to the development of a variety of tools that can help manage and exchange information related to the building environment. In this research, a new C2M tool known as M-DIC2 has been introduced, which can be used to connect the various models in the BIM model environment [60]. This paper aims to explore the various aspects of the construction management of heritage buildings through the use of BIM technologies. It includes the creation of parametric models of the structures and the multiple phases of restoration work [61]. The data collected during the study can be used to create a variety of H-BIM models and improve the understanding of the building's performance. In addition to the structural integrity and outer geometry surveys, the data can also be used to analyze the building's history. This method can help in the development of a more accurate and comprehensive understanding of the building's condition [62].

This research study explores the utilization of digital documentation technology for the conservation of socio-religious cultural heritage. The goal of this study is to find a solution that would allow experts to document the existing building using an information model. This would allow them to improve the efficiency of the historic building restoration process and create interactive programs that would enhance the presentation and operation of the buildings. The HBIM model created with Revit allows specialists to dynamically modify parameters, integrate diverse data sources, and perform detailed analyses, facilitating effective preservation and management of historic buildings.

Apart from being able to expand the scope of the complete program, this solution would also allow users to manage and interact with the data collected by the historic building model. This would help improve the efficiency of the building restoration process and prevent deterioration. The basic aim is to develop a sustainable framework of conservation in the Southern Punjab Region of Pakistan, specifically for the building typology of shrines but would be applicable to other historic buildings with some amendments in required parameters.

2. Materials and Methods

HBIM is a great tool for creating 3D models of historic buildings, but it can be very challenging to implement due to the unique considerations involved. This guide aims to provide a comprehensive overview of the various steps involved in applying it to these structures. This methodology [63,64] is adopted for digital documentation of structures. Step by step methodology as shown in Figure 1 has been explained as:

Step 1—Site Selection: The first step was site selection, which was carried out according to criteria developed in the research. There were three categories of shrines for developing 3D Revit models through scan-HBIM technology. This shrine falls under the 2nd category, which was "A shrine with damages and not in a good condition", so, this shrine of Shah Yousaf Gardez was selected as a case study under this category.

Step 2—Initial Survey/Visual Inspection: The initial survey was carried out by visual inspection of the shrine to monitor its current condition. All the measurements—like length, width, height, and other structural and non-structural members of the structure—were taken carefully to facilitate further work. The condition of the shrine was noted to identify and document visible conditions and areas of concern. This includes noting structural issues, material degradation, and any visible alterations.

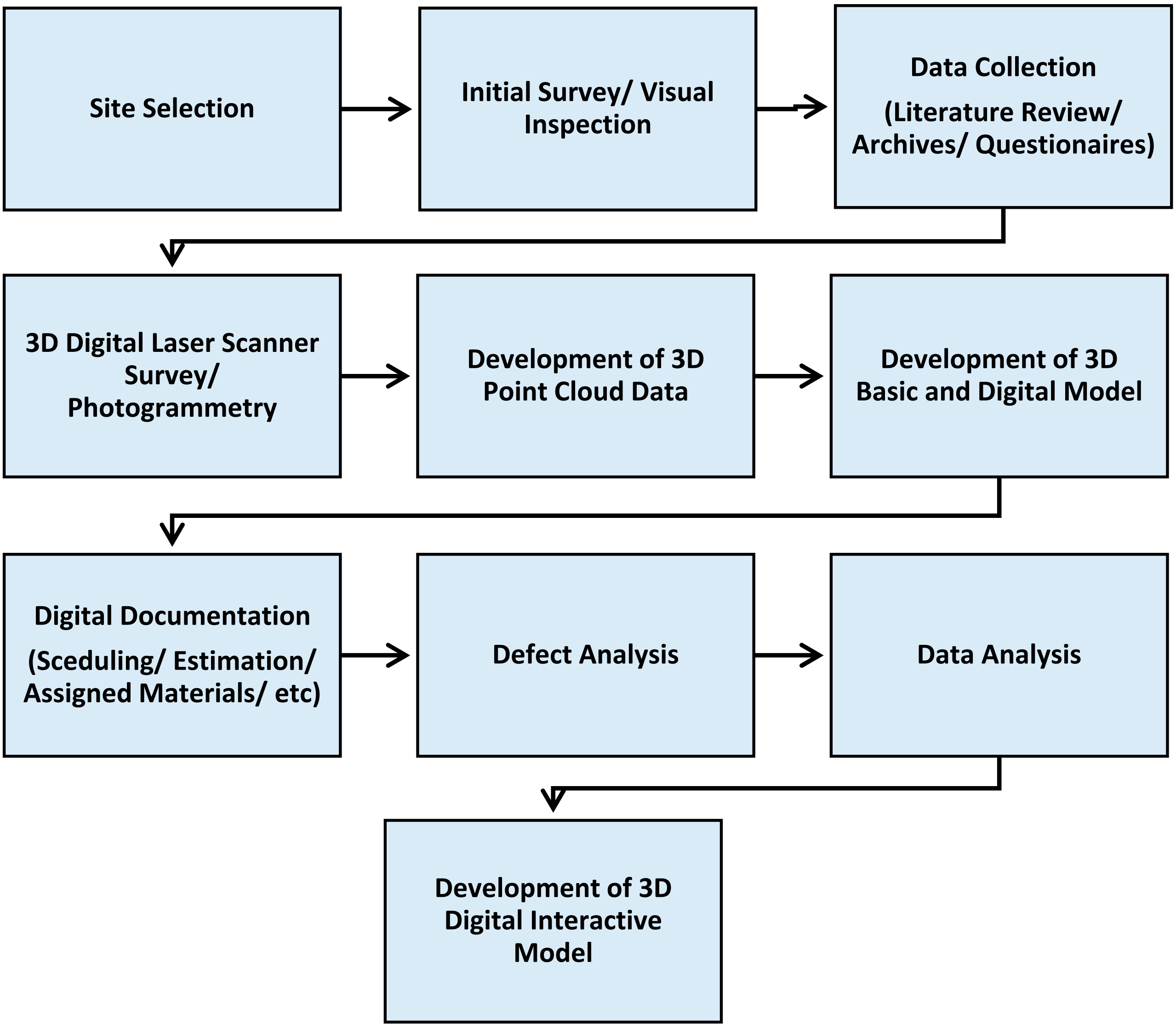


Figure 1. Flowchart of research methodology.

Step 3—Data Collection: Initial data collection was conducted by gathering historical records, photographs, drawings, and previous archives/documentation related to the shrine. These data were collected through the study of relevant books, research papers, and archives preserved by the caretaker of the shrine and also the relevant authorities responsible for safeguarding such historic buildings. These historical data not only provide context and background information but also details of conservation work performed on the selected shrine over time. Some 2D drawings were also found.

Step 4—Digital Laser Scanner-Survey: The main survey was carried out by using a 3D digital scanner. Performed site calibration to ensure the scanner was properly set up and aligned. This involves leveling the scanner and setting up reference points to improve accuracy. The size and geometry of the shrine required six scans with a 3D laser scanner (outside and inside)—one scan from the west side, the second from the southeast side, the third from northeast, and the fourth from the north. Two further scans were performed inside the shrine. Each scanning position was carefully selected to capture detailed features and avoid obstructions. The scanning process was continuously monitored to verify data quality and completeness.

Step 5—3D Point Cloud Data: Executed the scanning process, capturing millions of data points (point clouds) representing the shrine's surfaces and structural elements in three dimensions. It was carefully ensured that each scan overlapped with adjacent scans to facilitate accurate stitching. The point cloud data were transferred from the scanner to a computer for further processing. At this stage, it was ensured that all data were backed up and organized systematically for ease of access.

Step 6—Development of Model: Used specialized software (such as Autodesk Recap, Recap-Pro) to align and merge the individual point clouds from different scans into a single, unified 3D model. This involves matching reference points and ensuring the entire structure is accurately represented. The data were then cleaned, removing any extraneous points that did not represent the actual structure. The processed point cloud data were imported into HBIM software (Autodesk Revit) and used to create a detailed and accurate 3D model of the shrine.

Step-7—Digital Documentation/HBIM modeling: All relevant components, including architectural and structural elements and components, were modeled. Each component was ensured to be accurately represented and documented. This shrine contains brick masonry walls covered with lime plaster and embellished with kaashi tiles or blue multani tiles on the exterior, while the interior is decorated and covered with marble tile and mirror work on the walls, which is called aina kaari. The ceiling is wooden. All the interior, exterior, floor, and ceiling tiles were carefully documented and developed in shapes, sizes, patterns, colors, materials, and textures. The calligraphic tiles were also developed with the same inscriptions.

Step-8—Data Analysis and Defect Analysis: Detailed architectural drawings, floor plans, sections, and elevations were produced from the HBIM model. This included annotations and references to historical data and visual survey findings. All the defects identified in the initial survey were carefully recorded and tabulated in structural defects and non-structural defects on different components whether they were structural or non-structural. The graphical representation clearly describes the percentage of defective components of the shrine, which develops a detailed defects analysis. By using these data, all the defects were carefully and precisely created on each side (exterior and interior) of the shrine. These defects were created accurately in size, shape, and area for each defective tile. These were analyzed again to verify which tiles needed to be changed and which would be preserved in the same condition. This part is very strongly beneficial for the conservation work. The HBIM model was used to develop a conservation plan, identifying areas requiring restoration or preservation and proposing appropriate conservation methods based on the detailed documentation.

Step-9—Digital Interactive Model: This scan-HBIM technique resulted in a 3D digital interactive model of the shrine of Shah Yousaf Gardez. This model provides access to detailed information about specific elements. It is easy to view different parts of the shrine to monitor its current condition in order to make decisions for future conservation work. This model also facilitates updating the condition of the shrine with time. It creates a digital archive of all collected data, including point clouds, HBIM models, historical records, and documentation. This archive will serve as a valuable resource for ongoing and future conservation efforts.

2.1. Site Selection—Shah Yousaf Gardez Shrine

Shah Muhammad Yousaf Gardezi, famous as "Yousaf Gardezi", was born in Gardez, near Ghazni in Afghanistan in 450 AH/1058 AD. He arrived in Multan sometime between 1086 AD and 1088 AD and settled where Bohar Gate stands today. After residing in Multan for 50 years, he died in 1136 AD, and the shrine was constructed in 1152 AD—14 years after his death [65]. The Shrine of Shah Gardez is shown in Figure 2.

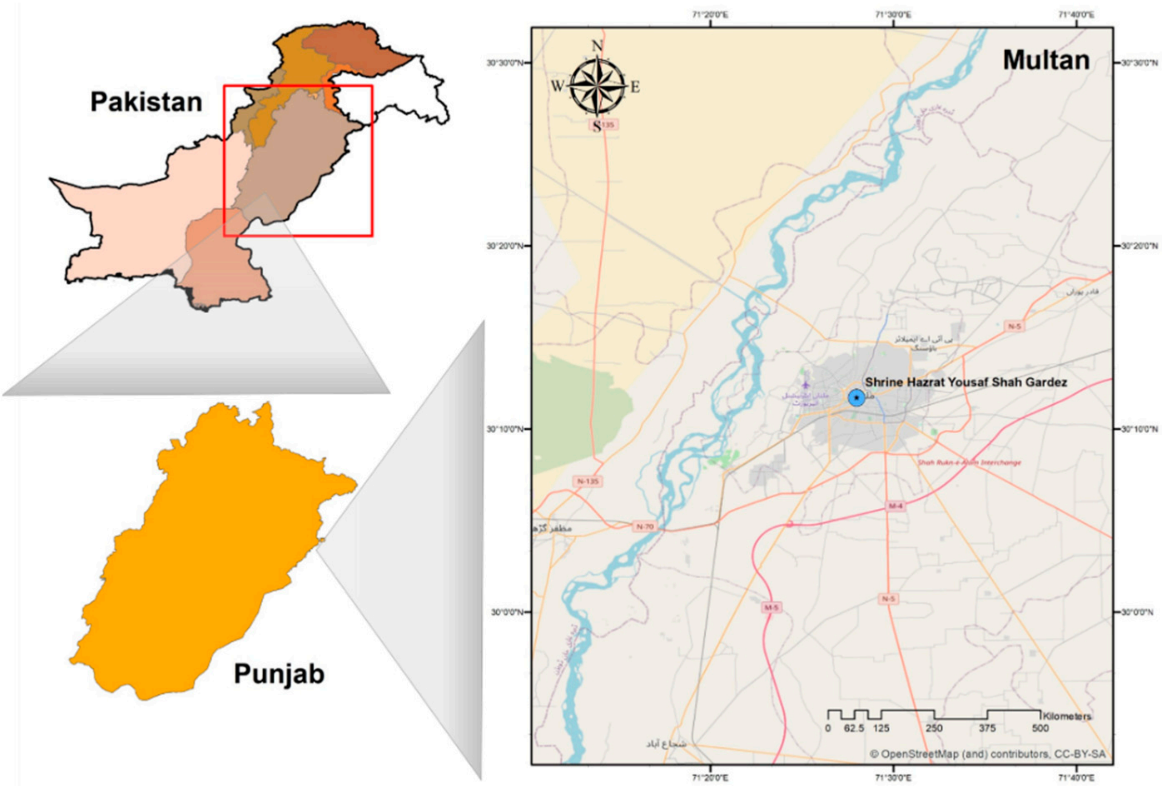
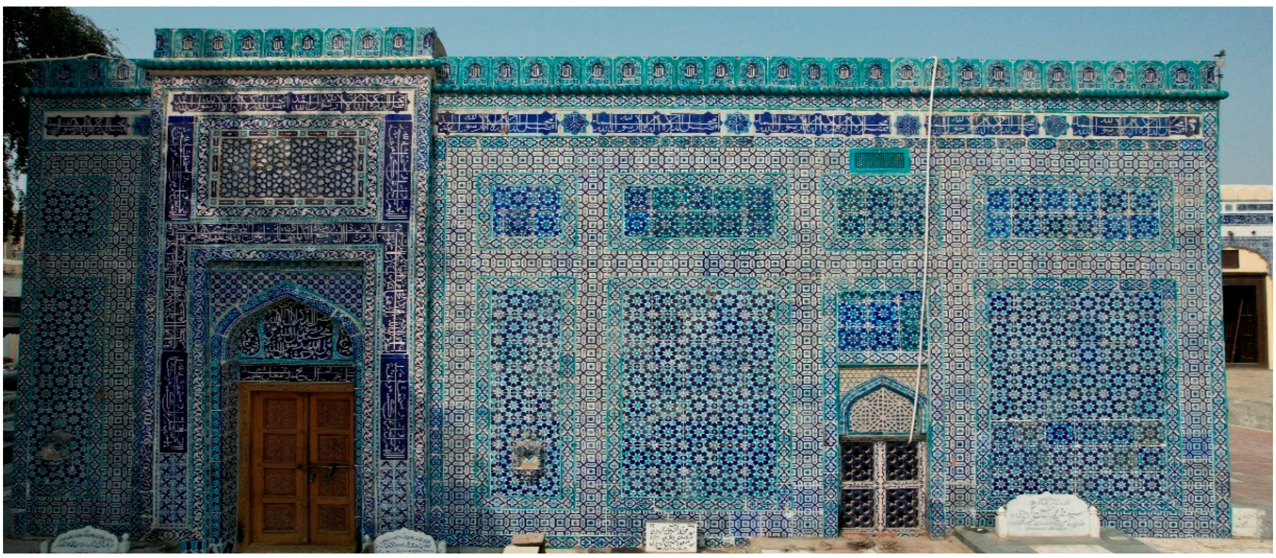


Figure 2. Location map for the Shrine of Shah Yousaf Gardez (Multan).

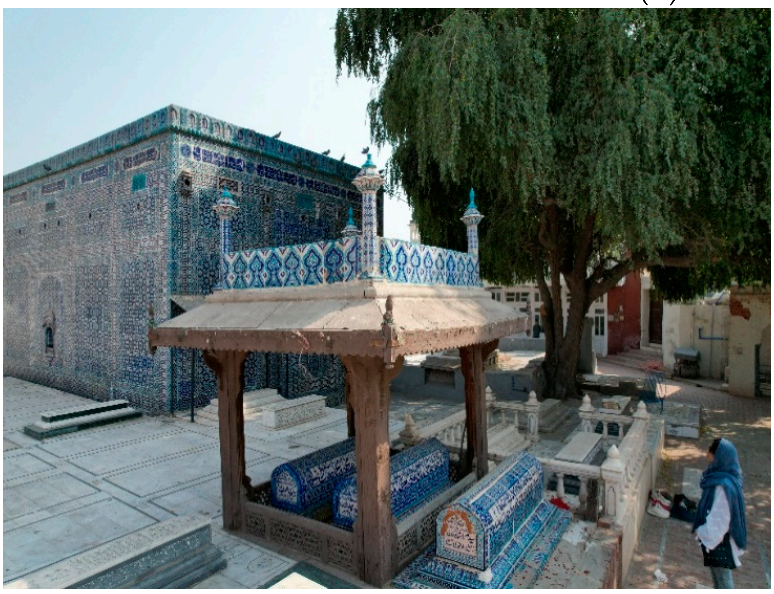
This flat roof shrine is 37 feet long and 23 feet wide with a height of nearly 20 feet. The exterior walls are entirely covered with glazed blue Multani tiles, and the interior is covered with aina kaari (mirror work) in the present time. The interior wooden ceiling is also decorated with Taqseem Bandi (technical local term). The building in its present state, particularly in ornamental features, is the result of various renovations, some alterations, and interventions [65]. The historic pattern of the structure is shown in Figure 3.



(**a**)

Figure 3. *Cont*.

(**b**)



(**c**)

(**d**)

Figure 3. Case study—shrine: Shrine of Shah Yousaf Gardez (Multan). (**a**) Front view, (**b**) inside view, (**c**) side view, (**d**) entrance.

2.2. Evolution of the Shrine

The shrine was built in 1152 AD. The main door is on the left side of the south façade, and an arch frame window occupies the right side. The frame of the main entrance door is projected outward to some extent and has a decorated arch with a patterned screen called a jali. Above the arch, there is a rectangular decorative panel in kashi work, which articulates the main entrance with two rectangular niches carved on each side. A window on the right side is crowned with an arch and is screened from the courtyard with a porous jali. The cornice of the hall is a miniature replica of a fort's battlement. There is a calligraphic band below the cornice. The current building is a restored version of the original structure. It is evident from the photographs the building passes through many centuries carrying its legacy and the uniqueness of its form and architecture. Figure 4a shows that the exterior envelope of the building was covered with tiles. All the components seem in the same place in the same form as are in the present state. The shrine is not in good visible condition—tiles are eroded, and faded color depicts its condition to be conserved.

(**a**) (**b**) (**c**)

Figure 4. Historic appearance of the shrine in the years (**a**) 1800, (**b**) 1988, and (**c**) 2024.

In Figure 4b, the exterior is covered with tiles all around, with calligraphic panels similar to the present state in Figure 4c. In 1988, the building façade and exterior were the same as now except for some components, and a simple door of wood in light green paint was visible. This was replaced with a carved wood door in a brown color. The components to place oil lamps are visible in the first two photographs but were removed in conservation work performed later.

2.3. The Shrine of Shah Yousaf Gardez, Multan: From Survey to Conservation Plan (Scan-HBIM)

2.3.1. 3D Laser Scanning and Photogrammetry

A survey with a 3D laser scanner was carried out to capture the regular shape and form of the shrine. The size and geometry of the shrine required six scans with a 3D laser scanner (outside and inside). 3D laser scanner was used to collect data for model development (Figure 5).

Figure 5. 3D laser scanning instrument.

The final point cloud file is generated by millions of points. The instrument was placed in various positions to the northeast, west, south, and inside of the shrine. The raw data were extracted in different formats as per the requirement to use RCP and RCS files.

The survey of the shrine included historical and architectural analysis, identification of materials, technological aspects, and some information from non-destructive testing. This was an absolutely more useful way to generate the plans and sections, but for such an HBIM project, it becomes fundamental. Indeed, 3D laser scanning and photogrammetric techniques created highly detailed and accurate point clouds or meshes, which resulted in visual representation of the selected shrine and revealed the external layer of its components and elements. Establishing a stable reference system within the tomb and its surroundings was required to connect the different survey strategies—aerial and terrestrial photogrammetry and laser scanning. Scan data of Shah Gardez are shown in Figure 6, and aerial photogrammetric outputs (point clouds) are shown in Figure 7.

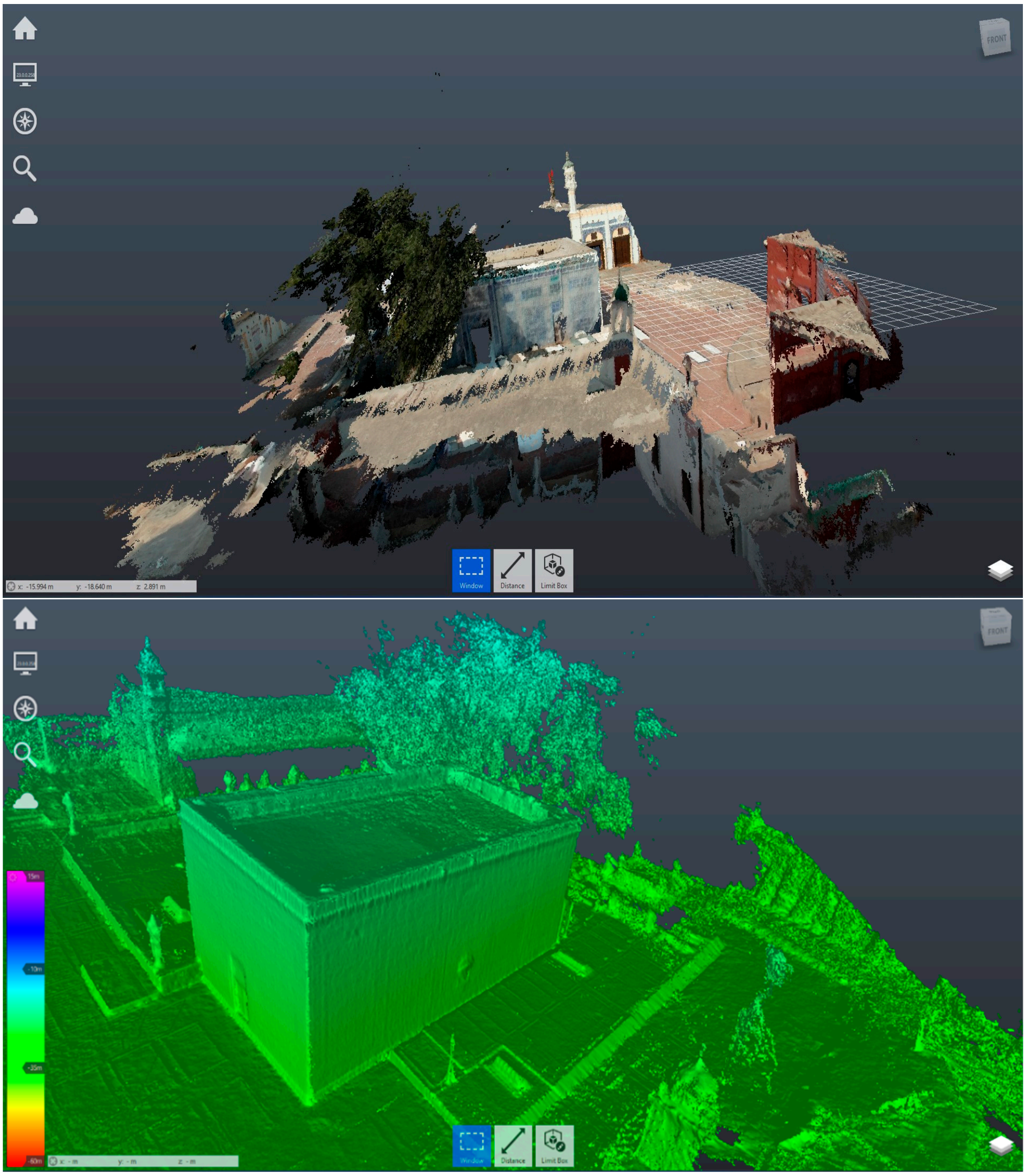


Figure 6. Survey data (top, northeast side of shrine Shah Yousaf Gardez).

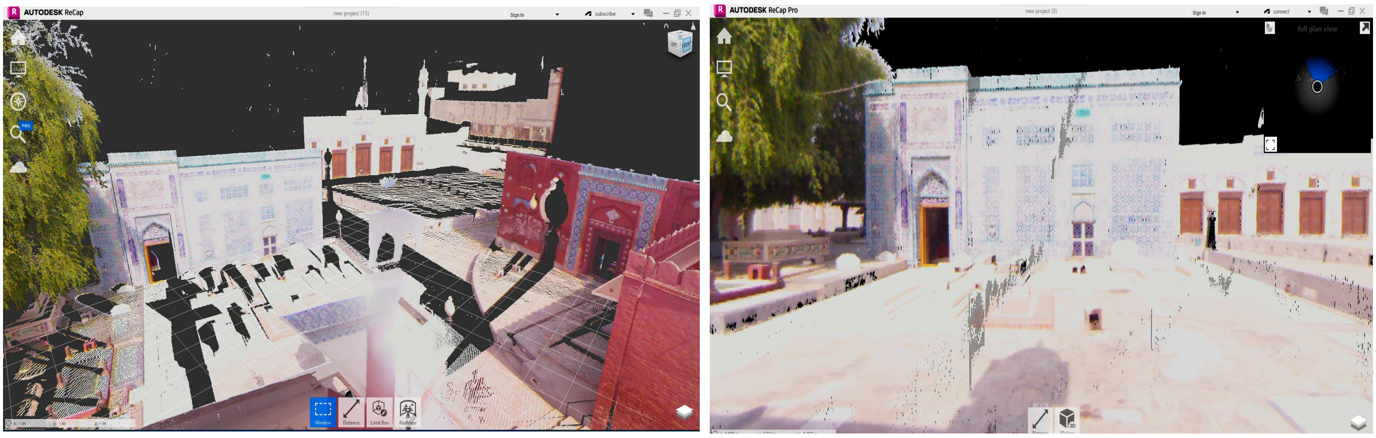


Figure 7. Aerial photogrammetric outputs (point clouds).

2.3.2. The Architectural Representation, Building Archaeology, Digital Preservation, and Scan-to-HBIM Process

This shrine is a simple rectangular shaped building. It differs from the other examples of historic buildings of the same time. It is a single-story flat-roof building that stands within a closed courtyard. Its elevation consists of four vertical load-bearing walls, the sole relief being formed by a slightly projected oblong portion to frame the doorway. It contains the mihrab on the interior side with calligraphic mirror work and framed Surah Yaseen from The Holy Quran, which glorifies the overall impact of the inner side decoration and setting. In Persia, common in other historic buildings of the same class, it relies entirely upon its effect. These effects not only deal with the usual features in architectural compositions—such as a variety of planes in contrast to passages of light and shadow, or the definition of moldings—but also with the brilliant blend of color produced by the ornamentation on its surface of encaustic tiles, which encase its outer walls as a whole. Most tiles have probably been renewed at a later time, but the patterns are still the same. It includes mainly geometrical, inscriptional, and floral designs, which are rare and indicate that the law of the Prophet (PBUH) prohibiting natural forms was strictly observed [66].

The basic 3D model was developed based on the accurate dimensions on Revit. All the levels were adjusted properly, as shown in Figure 8. Then, the point cloud data were overlapped with the model to clarify all components and distances. The scanner used in this research is efficient, but to improve the quality of scan data, aerial videos and photographs were taken by a drone camera with 48 MP resolution. The videos were converted into photographs to develop a model by using Adobe Premiere Pro. The images were imported into Agisoft, and a file was created. This model was also layered with a point cloud model to enhance the features and details of the shrine. All the architectural components were developed as original components to preserve them precisely. Exterior kashi tiles, interior aina kari panels, floor marble tiles, wooden ceiling tiles, arches, ventilators, pigeon holes, oil lamp places, and calligraphic tiles were developed with very conscious details to compare to the originals. This approach allowed for the creation of a highly detailed and accurate 3D model that could be managed at architectural and structural scales without compromising the shrine's integrity or omitting any crucial details.

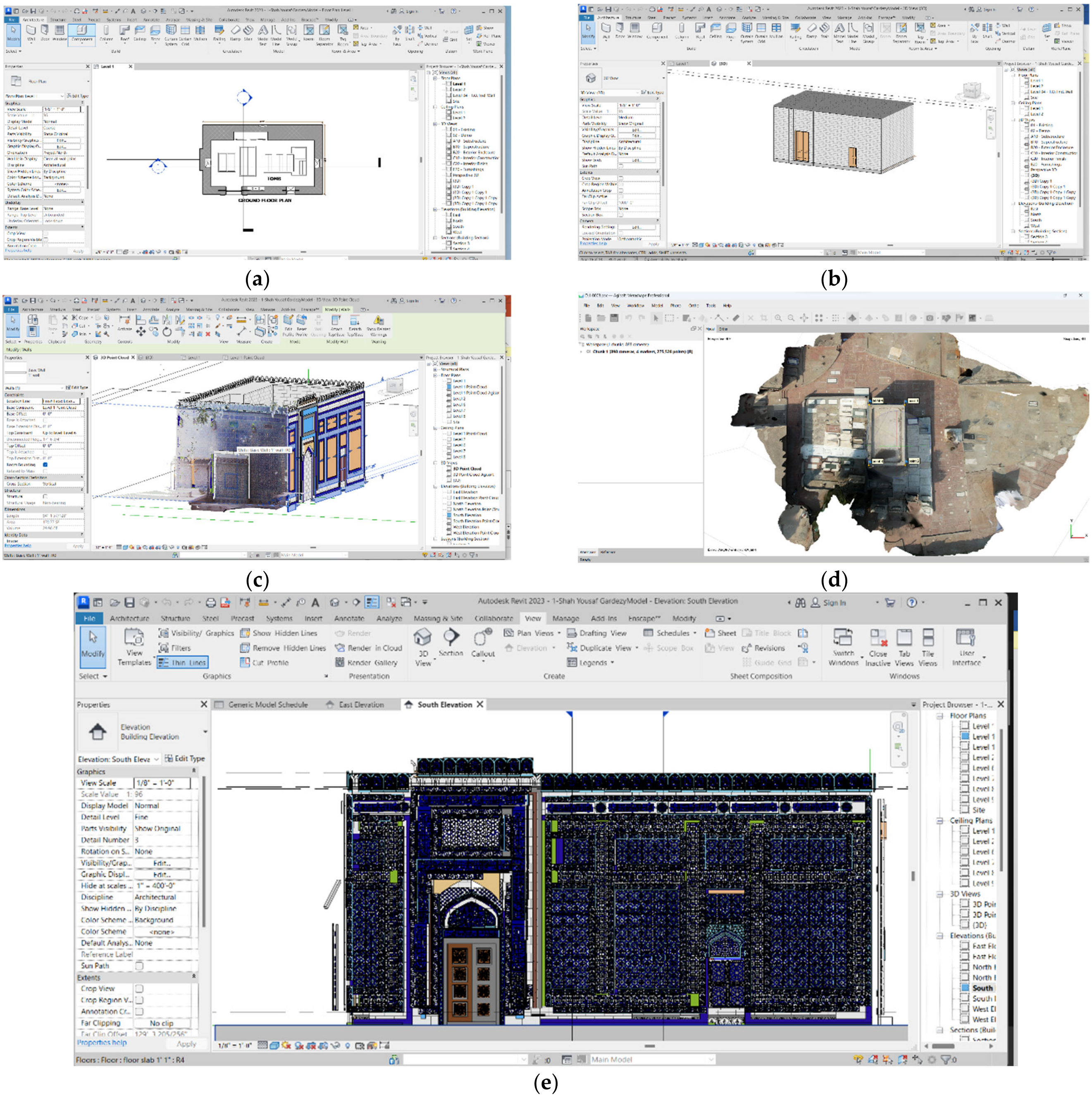
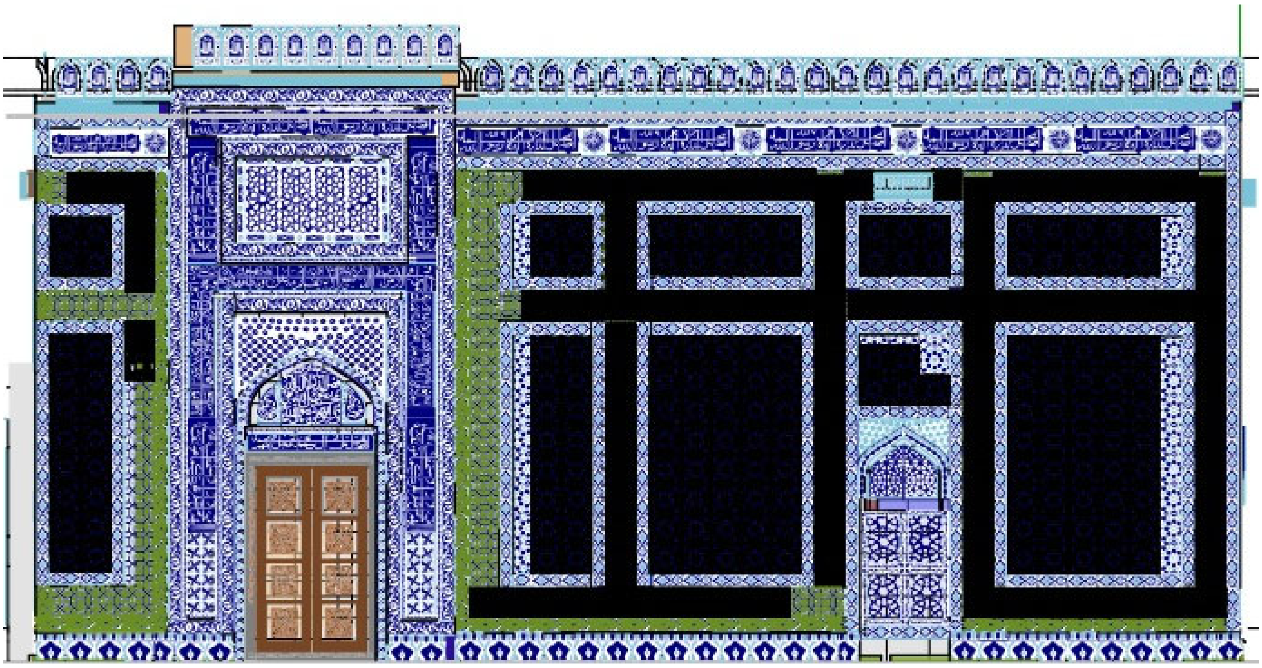


Figure 8. *Cont.*



(**f**)

Figure 8. (**a**) 2D drawings on BIM-Revit, (**b**) 3D drawings on BIM-Revit, (**c**) point cloud data with 3D model, (**d**) point cloud model (with Agisoft), (**e**,**f**) 3D model (digital) of the shrine of Shah Yousaf Gardez, Multan.

Digitization has become much more prominent in digital representation and to balance not only the traditional practices but also future-oriented opportunities which are considered most important. The effective utilization of digital and traditional forms of representation is necessary and emphasizes the value of digital representation as a useful knowledge tool during the modeling phase. This recognition leads to the provision of exploring, creating, and managing a significant relationship in the forms, materials, and spaces. Identification, analysis, interpretation, and comprehension of "unique" artifacts and materials are vitally important to achieving accurate and rich three-dimensional (3D) representation [67].

The survey data was combined with graphic work to interpret 2D and 3D design models, careful examination of archives and other sources along with the present condition of the shrine. This digital modeling process needs connections in different areas which range from heritage conservation to propagating tangible and intangible values associated with the shrine.

Figure 9 shows details of 2D and 3D architectural models of some tiles and panels on the exterior or interior side of the shrine. For this purpose, separate families are generated for each tile and panel, such as wall family, window family, door family, and ceiling family. All tiles present on the walls, whether on the exterior side or interior side, are developed as separate families. In the process of developing Revit families, a family template was selected. Then, all the parameters were planned to create the required accurate geometry. All the families of artefacts were assigned exact material, RGB, and dimensions to create a family type.

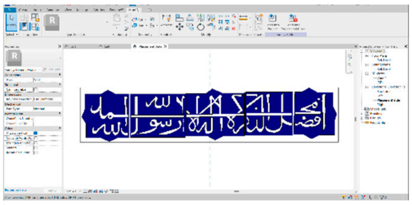
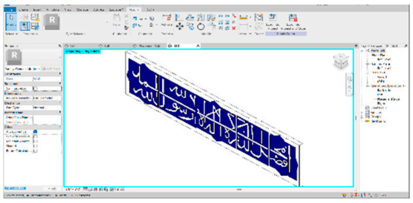
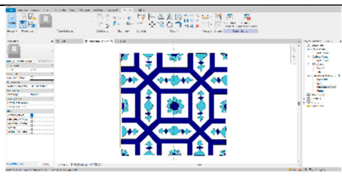
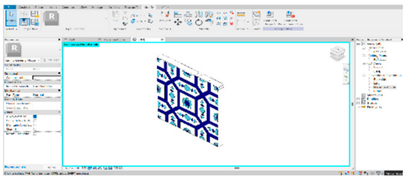
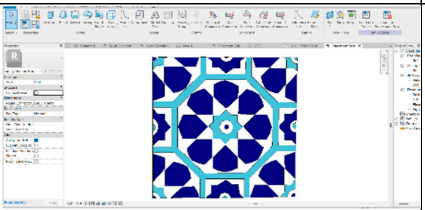
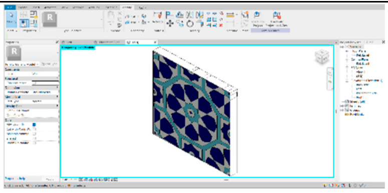
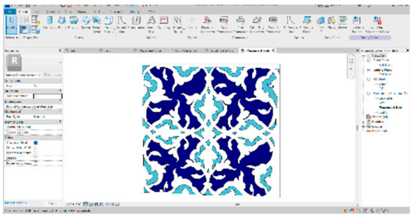
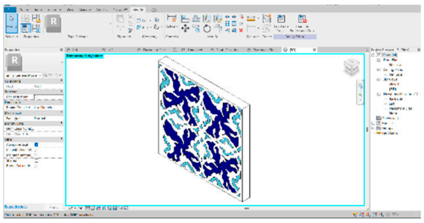
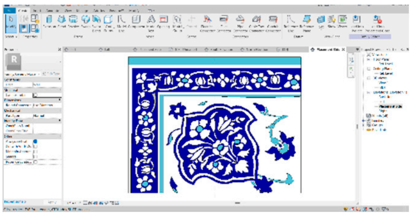
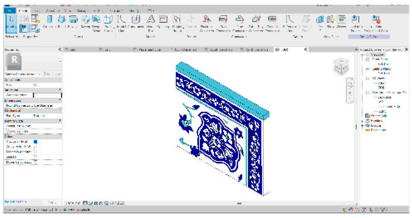
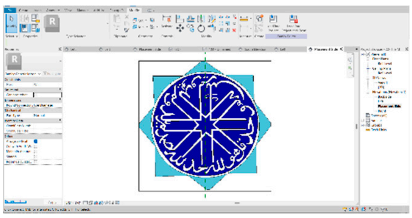
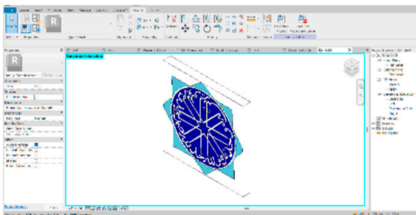
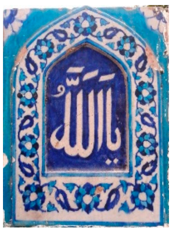
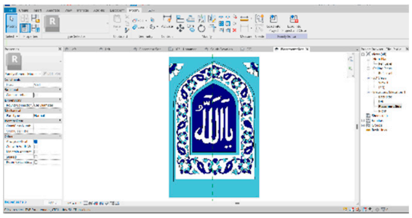
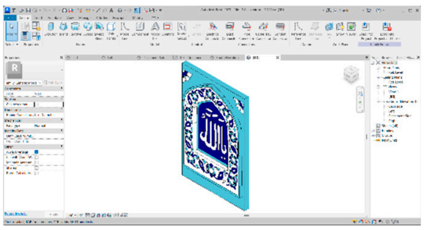
Tile	Original artefacts	Revit model	3D
Tile-L			
Tile-A			
Tile-B			
Tile-G			
Tile-R Back-side			
Tile-M			
Tile-P			

Figure 9. *Cont*.

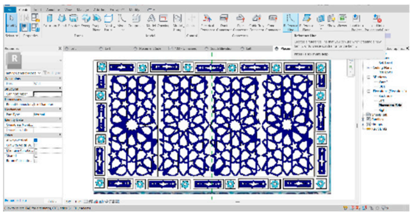
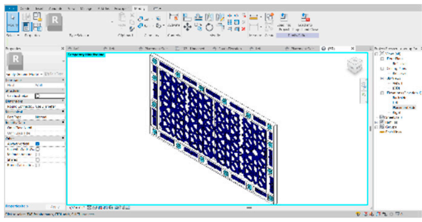
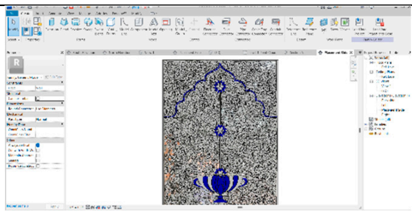
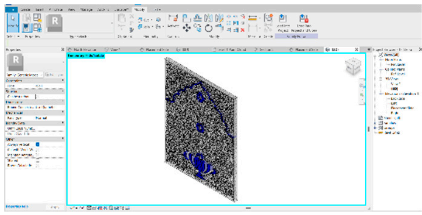
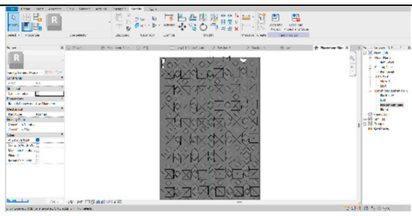
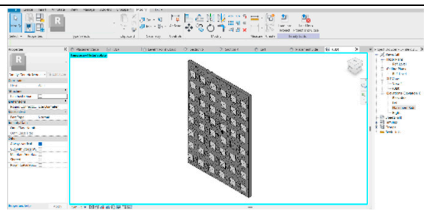
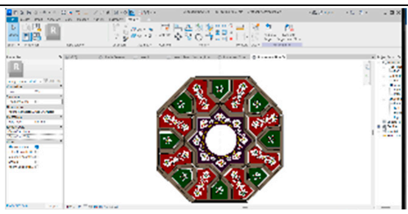
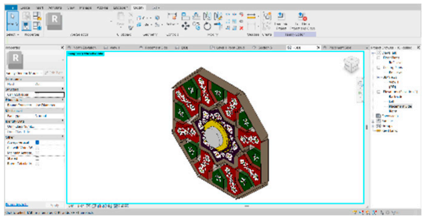
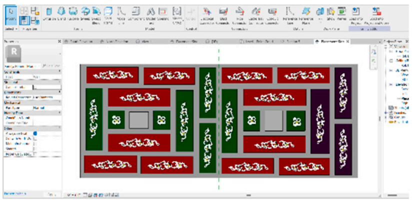
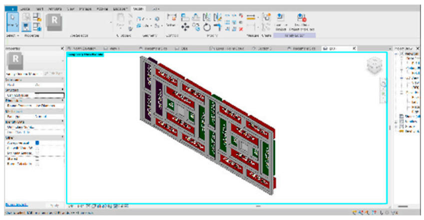
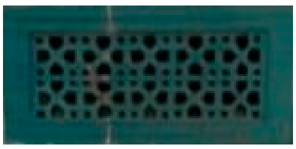
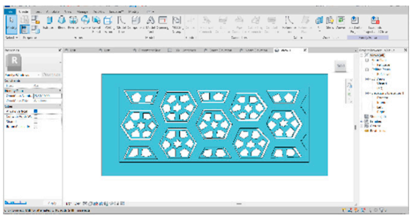
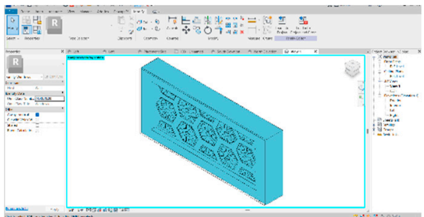
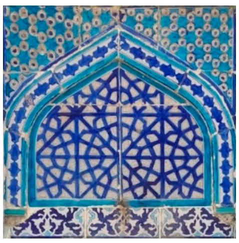
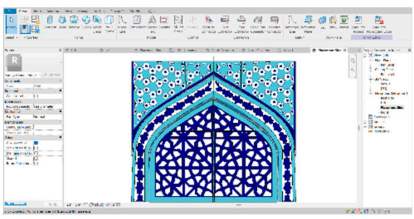
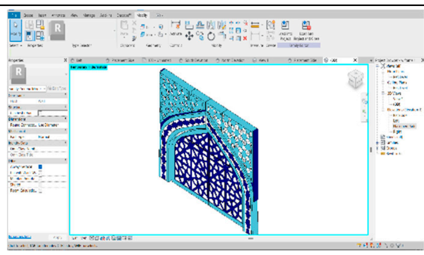
PanelDoor up			
Tile-a (interior)			
Tile-c (2′1″ × 3′ interior)			
Ceiling Floral Tile			
Ceiling Rectangles Tile			
Ventilator V3			
W (window) Frame 1			

Figure 9. Original tiles and panels vs. model design (2D and 3D).

Revit families allow interaction with the project components during the procedure of 3D modeling and the development of individual drawings with extensive information about dimensions and layouts. Revit families were inserted to develop an accurate model. Any change to a Revit family type will be updated in every instance of that type throughout the project design. For example, when the width or height design pattern, or color of a tile type is changed in one place, all tiles of that type will be modified automatically and instantly throughout the model design.

After creating and developing all required families, all components—including tiles, windows, doors, ventilators, pigeon holes, oil lamp places, calligraphic kashi tiles, mirror work panels, floor tiles, ceiling wooden tiles, arches, and calligraphic aina kari (mirror work) tiles—were placed accurately on their precise places in the model with high care. Instead of the architectural model, the structural details are also incorporated in the model as contained within the original shrine. This all results in a 3D interactive model which is the development of the digital model of the Shrine of Shah Yousaf Gardez, Multan. This shrine is not only a socio-religious place but also has marvelous architecture which depicts the features and values of its time. This digital model of this shrine is an effort to protect this valuable asset and to preserve it digitally for the upcoming generations in its original historical, cultural, structural, and architectural form. Moreover, this digital model provides details to conserve the shrine accurately. The estimation of the material is generated in scheduling. Figure 10 shows the overall process of the development of this 3D digital model from the original physical shrine through the point cloud model.

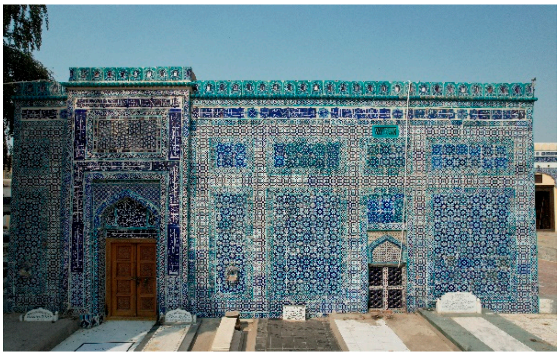
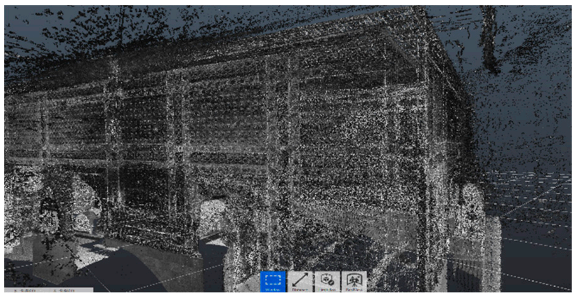
Side (E/I)	Exterior	Interior
Original		
Point Cloud model		

Figure 10. *Cont.*

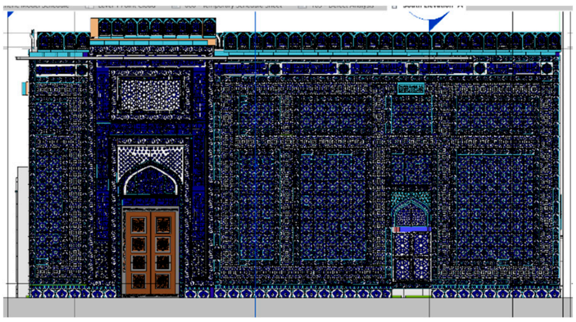
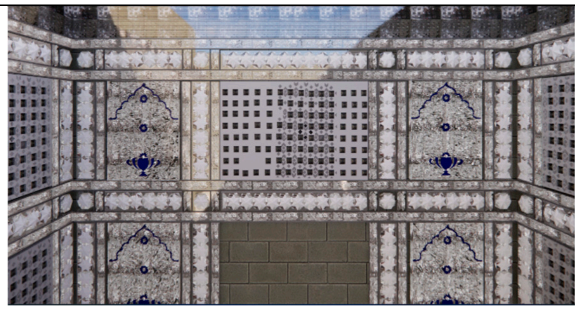
3D Digital Revit model		
E/I= Exterior/Interior		

Figure 10. Development of 3D interactive model (digital model) of the Shrine of Shah Yousaf Gardez.

3. Results and Discussions

3.1. Identification and Analysis of Defects

Conservation of historic buildings is a prominent matter about both from cultural and economic values of any society. Information regarding built heritage is pivotal to planning any remedial measures or conservation process. Various important causes of defects are sun exposure, heating and ventilation, excessive moisture indoor production, and dampness [68].

Defects can be defined as faults on anything that reduce its perfection, while damage in a building occurs when any structure or its material, equipment, or elements are not properly functional [69]. Construction defects are considered failures or imperfections in the building's function, performance, or user requirements that can occur in its fabric, structure, services, or other facilities [70]. Moreover, a lack of anything which is necessary for completeness is called a defect and simply referred to as a shortcoming [71]. Historic buildings are formed in the past and contain high architectural and historical values. These require regular care, protection, and maintenance to preserve their historic, archaeological, aesthetic, spiritual, social, and economic values [72]. There are different types of defects that can be identified and classified by its elements, usually the exterior walls, interior walls, columns, doors, windows, roof, floor, and many others components [73]. The Shrine of Shah Yousaf Gardez is 871 years old and has faced climatic effects through the centuries. The defects observed in the building include structural defects like settlement, cracks in walls, cracks in roof, cracks in floor, and cracks in lintels or openings as well as non-structural defects, such as plaster cracks, spalling, erosion of bricks, peeling of paint/plaster, discoloration, termite attack, efflorescence, patching, dampness and swelling. Table 1 provides the detail of structural defects and non-structural defects present on each side, roof, and floor of the shrine. The number of defects on structural and non-structural components is shown in Table 2, which provides the details.

Table 1. Detail of structural defects and non-structural defects present on each side, roof, and floor of the shrine.

Structural Defects in Shrines									
Sr. No.	**Side Code**	**EE (Exterior East)**	**EW (Exterior West)**	**EN (Exterior North)**	**ES (Exterior South)**	**IE (Interior East)**	**IW (Interior West)**	**IN (Interior North)**	**IS (Interior South)**
	Shrine	**Hazrat Shah Yousaf Gardez**							
	Age (years)	871							
1.	Foundation Settlement	No	Yes (very minor due to dampness)	Yes (very minor due to dampness)	Yes (very minor due to dampness)	No	Yes (very minor due to dampness)	Yes (very minor due to dampness)	Yes, some extent
2.	Cracks in walls (Vr./Hz. or any other)	No	No	No	No	No	No		Yes, in left-upper side panel
3.	Cracks in roof	No	No	No	No	Yes, on left corner	Yes	Yes	No
4.	Cracks in floor	No	No	No	No	No	No	No	No
5.	Cracks in lintels/openings	Yes	No	No	Yes, in window lintel	No	Yes, in arch	Yes, in mihrab arch	No
Non-Structural Defects in Shrines									
6.	Plaster/Wood Cracks	No	No	No	Yes, in wooden lintel of window	No	No	No	Yes, in wooden lintel of window
7.	Spalling	No	No	No	No	No	No	No	No
8.	Erosion	Yes, on some kashi tiles	Yes, on some kashi tiles	Yes, on different kashi tiles	Yes, on different kashi tiles	Yes	No	Yes	Yes
9.	Discoloration	Yes	Yes	Yes	Yes				
10.	Termite Attack	No	No	No	Yes, on window lintel	No	No	No	No
11.	Salt Attack/Efflorescence	Yes, on some kashi tiles	Yes, on some kashi tiles	Yes	Yes, on some tiles	Yes	Yes	Yes	Yes
12.	Peeling of Paint/Plaster	Yes	Yes, on some kashi tiles	Yes	Yes, some kashi tiles are peeled off	Yes	Yes, on some mirror panels	Yes	Yes
13.	Patching	No	No	No	No	Yes, one small mirror panel is patched off	No	No	No
14.	Dampness/Swelling	No	Yes	No	Yes, dampness	No	Yes, on right side mirror panel	Yes	Yes

Table 2. Number of defects on structural and non-structural components.

Shrine	**Number of Defects on Structural Components**						
Hazrat Shah Yousaf Gardez	Walls	Roof	Arches	Floor	Parapet Wall	Lintel	Total No. of Defects
	35	5	18	2	5	9	74
	Number of Defects on Non-Structural Components						
	Door	Windows	Ventilators	Drains	Pigeon Holes	Oil Lamp Places	Total No. of Defects
	1	8	6	1	8	1	25

Figure 9 shows the Eastern side of the shrine. In the first row, the exterior eastern side is focused on to explain the process of developing the identified defects precisely on their location as observed. In the second row, the interior eastern side of the shrine model is shown to express the process. It is evident from Figure 10 that the process of developing defects on tile-B on a certain area is basically an effort to make a precise digital model of the shrine which holds a unique identity as a heritage building. The size of the tile-B is $11'' \times 11'' \times 1''$, with a volume of 0.07 CF and 0.84 SF surface area. From Figure 10, the first layer of a defect can be observed—that is, erosion is created on the tile surface on exact place with the same affected area of i-e 0.27 SF. Then the second layer of efflorescence on same area is created. Its affected area is 0.01 SF. The third layer of peeled-off surface on the glazed kaashi tile is developed and has an affected area 0.06 SF. Similar defect layers are created inside on their exact positions. The same procedure is adopted on the whole building of the shrine to develop the analysis of defects. Defects found on structural components, like walls, roof, arches, floor, parapet walls, and lintels of the shrine. This shows that walls are more affected than other components. Calculation of these defects is mentioned in Table 2. Similarly, defects appear on non-structural components, like doors, windows, ventilators, drains, pigeon holes, and oil lamp places of the shrine building. The table shows that pigeon holes are more defective than other components. The details of structural defects and non-structural defects are given in Table 1. Figure 11 presents the overall procedure to create defects on each side/section of the shrine, inside and outside. Figure 11 shows images of the real building's eastern exterior side in its current state with defects as well as the Revit model of that side. The defects on this elevation are shown exactly on the places where tehey exist on the original building at the current time. The area of each defective kashi tile (exterior) and mirror work panel (interior) is exactly same as in reality. This is clearly discussed in Figure 12. This exact identification and placing of defects in the 3D model will lead to accurate estimation of the defective tiles, which must be preserved or restored in the conservation of this shrine.

The development of the defects on each exterior and interior sides of the shrine leads towards their categorization with regards to area of defect. Each defect is assigned a code to better understood. If the defective area is 70 percent or more than the total area of the tile, then that tile will be replaced in restoration work. This process further helps in easily preparing defective area estimation.

Figure 11. Exterior and interior eastern sides of the shrine, with and without defects, in the 3D model.

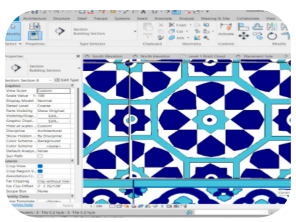
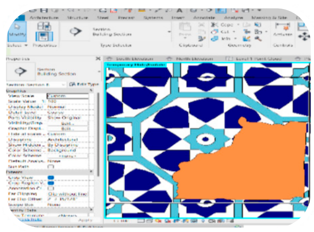
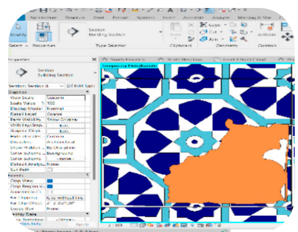
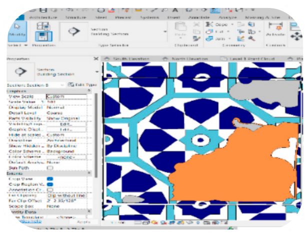
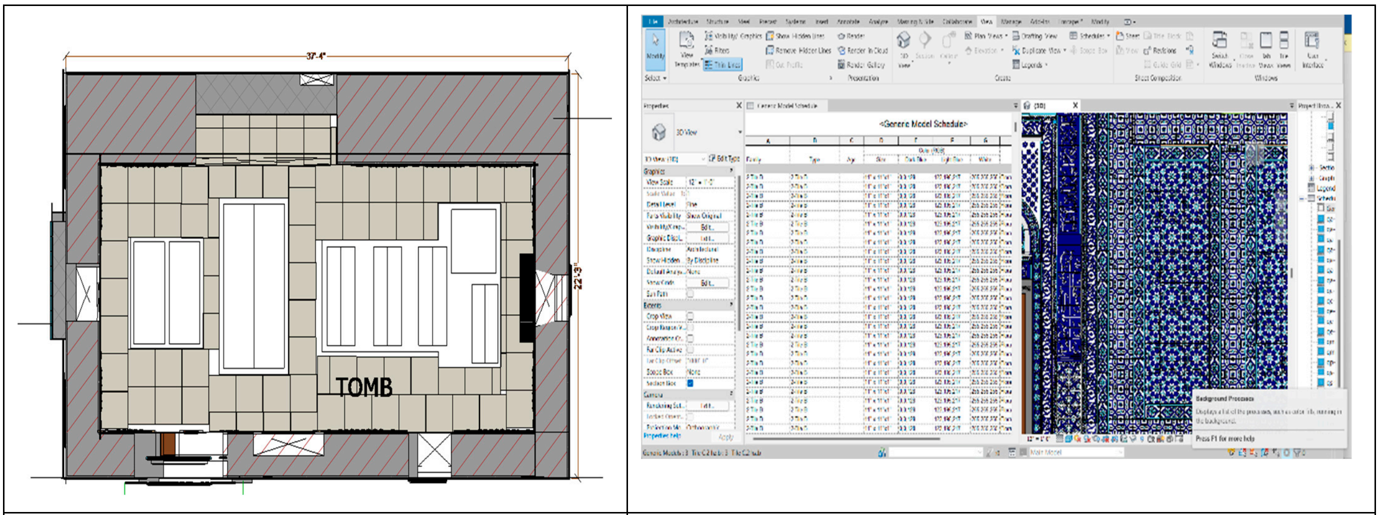
			
Tile-B	Tile-B with Erosion	Tile-B with erosion + Efflorescence	Tile-B with Erosion + Efflorescence + Peel off

Figure 12. Development press of defects on tile-B erected on the east side of the exterior phase, layers of defects on a tile.

3.2. Scheduling Quantities

After analyzing the defects, a detailed schedule of quantities was prepared. By this estimation, sheets are formed to estimate the building. Moreover, from this defect analysis, it is easy to make estimations of only those quantities which are required in the conservation process. This not only saves time but also costs on its preservation work. Figure 11 gives details of schedule quantity sheets developed for this particular shrine. Figure 13 describes the estimation of quantities through 3D Revit model which will further proceed towards its rate analysis.



(**a**) (**b**)

Figure 13. Scheduling quantities of the shrine; (**a**) tomb plan; (**b**) Cost Estimation software sheet.

Figure 14 shows the development of schedule/quantities using a 3D Revit model, which is an advanced method of estimation which will lead towards the planning of accurate restoration work of the shrine.

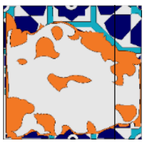
Orientation	Section	Family & Type	Size	Area (SF)	Image	Area of defects (SF)			Total Defective Area (SF)	70% of Area	Proposal forConservation
						Erosion (SF)	Efflorescence (SF)	Peeling (SF)			
East	1/104 (8)	Tile- C	5.5″ × 11″	0.42		E-D-err-10	E-D-eff-9	-	-	-	Edging with whitelime and white cement to avoid further decay
						0.07	0.01	-	0.08	0.29	
		Tile-C	5.5″ × 11″	0.42		E-D-err-1	-	-	-	-	Edging with whitelime and white cement to avoid further decay
						0.1	-	-	0.1	0.29	
		Tile-B-6.4 inc	6.4″ × 11″	0.48		E-D-2	E-D-eff-2	-	-	-	Will change
						0.36	0.05	-	0.41	0.34	
		Tile-B	11″ × 11″	0.84		E-D-3	E-D-eff-1	-	-	-	Will change
						0.62	0.42	-	1.04	0.59	
		Tile-B	11″ × 11″	0.84		E-D-err-6	E-D-eff-6	-	-	-	Will change
						0.25	0.01	-	0.26	0.59	
		Tile-B	11″ × 11″	0.84		E-D-err-5	E-D-eff-4	E-D-peel-1	-	-	Edging with whitelime and white cement to avoid further decay
						0.27	0.01	0.06	0.34	0.59	

Figure 14. Categorization of defective areas of tiles on east side of exterior phase.

3.3. HBIM to Support the Conservation Plan and Process

The decision to develop a BIM model of the Shrine of Shah Yousaf was made with a careful awareness of this advance digital procedure in terms of planning, designing, evaluation of the knowledge, conservation processes, and future maintenance. Heritage building information modeling, mostly referred to as HBIM, has established an important feature in research and practical activities. The advance techniques to collect data and process it with BIM authoring tools have facilitated the generation of more accurate digital representations of heritage buildings, which can then be used during preservation or conservation projects [74].

HBIM can be a powerful tool in preserving and documenting historic buildings. With HBIM, a digital model of the historic shrine is developed that not only captures its physical dimensions and features but also incorporates historical data, construction details, and even materials used. This allows visualization of the building in a digital format, making it easier to analyze, plan, and make informed decisions during the conservation process. All the processes are discussed above. This digital model is no doubt a basic part of the restoration or conservation process of recent times. HBIM can be used to simulate different restoration scenarios, explore the impact of proposed changes, and ensure that any interventions align with the building's historical significance. It can also help in managing and organizing documentation, such as architectural drawings, photographs, and reports, providing a comprehensive resource for future reference. Additionally, HBIM can facilitate collaboration among different stakeholders involved in the conservation process, allowing them to share information, exchange ideas, and work together towards the common goals of preserving the built heritage and developing a framework for conservation of socio-religious institutions of south Punjab, Pakistan.

4. Limitations and Future Recommendations

The limitations of historical research include the lack of accurate documentation and as-built drawings for buildings. This can be challenging to reproduce in a digital model. Due to the complexity of the construction methods and architectural details involved. Creating detailed HBIM models can be expensive and time-consuming, especially for large historic structures.

The compatibility of different HBIM software may be an issue, and integrating data from different sources can be hard. Additionally, there are no standardized protocols or guidelines for creating models, which can result in inconsistencies in their representation and capture.

Digitization of historical documentation raises ethical issues, such as data privacy and the risk of unauthorized use. In the future, recommendations will call for establishing HBIM model development guidelines that can help ensure interoperability and consistency. Advancements in technology, such as photogrammetry and 3D laser scanning, can increase the efficiency and accuracy of data gathering for HBIM.

In addition to interoperability, more efforts should be made to improve the integration and exchange of data between different HBIM software. Tools for analyzing building performance can also be integrated into the system to provide valuable insight for sustainable practices.

Training and capacity building initiatives for stakeholders can help improve their understanding and skills in utilizing HBIM for historic structures. Implementing ethical guidelines for the utilization of digital historical documentation can also ensure that technology is being used ethically. Adopting long-term preservation strategies can help safeguard the integrity and accessibility of HBIM models with the help of data management plans and digital archiving.

5. Conclusions

In this study, for historic building digital documentation, the integration of photogrammetry and 3D laser scanning into the preservation was used. Monitoring shrines as a cultural heritage is an exciting advancement. It helps to ensure that these assets are safeguarded for future generations while also making them accessible to a wider audience. Pakistan, no doubt, is blessed with a tremendous legacy of its rich heritage, which includes some unique architectural and historical values.

Historic buildings of any country are symbols of its national identity, so heritage buildings should be conserved well as important monuments to ensure the extended life spans of such buildings and to ensure continuity in the functions of these buildings for future generations.

A digital model is a virtual replica of the physical asset—in this case, the Shrine of Shah Gardz, which includes detailed information about its structure, materials, and historical context. A digital model can assist in shrine conservation by capturing the current state of the shrine in detail. This includes architectural features, artwork, and intricate details that may be at risk of deterioration over time.

This documentation ensures that valuable information is preserved even if physical changes occur. It is possible to simulate and analyze various conservation scenarios. This also helps to understand how different interventions may impact the shrine's structural integrity, aesthetics, and historical significance. By virtually testing restoration techniques or material choices, experts can make informed decisions before implementing them in the physical world.

Models can also serve as monitoring tools to track the condition and performance of the shrine over time. By integrating sensor data, one can monitor factors such as temperature, humidity, and structural movement. This real-time information can alert conservationists to potential issues or the need for maintenance, allowing for proactive intervention. It can be used to create immersive virtual experiences, allowing people worldwide to explore and learn about the shrine's history, architecture, and cultural significance. This promotes awareness and appreciation, fostering a sense of collective responsibility for its conservation. In developing countries, like Pakistan, it is the need to develop such processes and methodologies to safeguard our National historic assets.

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