DIGITALLY DOCUMENTING BUILT HERITAGE USING T. L. SCANNING. THE MAI EIDAAN COURTYARD, LAHORE, PAKISTAN

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1. Introduction

Historic monuments and open spaces are fragments of urban built heritage that play a vital role in the sustainable development of historic cities. Unplanned urbanization has deteriorated the urban fabric of old cities, and modern interventions have entirely transmuted the historic environment [1]. The constant deterioration of landmark properties due to natural occurrences and human activities has forced the conservation community to find new technical and concrete solutions for the conservation, restoration, rehabilitation, regeneration, and redevelopment of architectural and urban heritage [2].

The urban built heritage of the historic core of Lahore is in danger due to various factors, such as environmental, climatic, botanical, biological, and entomological issues [3]. In addition to these natural agents, human activities also damage the historic character of the old city of Lahore [4]. The historic city of Lahore has been used by intruders and invaders adaptively, resulting in the loss of precious stones and metals [5]. However, the cultural and historical values of the city articulate the stories of the past and educate the future generation about the progress made by earlier generations. Whatever remains is a national asset and must be safeguarded to maintain our national identity [6]. The historic urban landscape (HUL) and form of historic cities are transformed due to the changes in life patterns and responses to various cultures and communities [7]. For ages, cities have been a source of history, art, architecture, culture, and rituals because cities are not just physical places to live in; they are vivacious entities and dynamic spaces that showcase human achievements through art, architecture, and cultural heritage. The historic environment needs to balance the heritage

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conservation with socio-economic development in the area [8].

For the last few decades, conservation experts have inevitably been using digital technologies to get the maximum from the digital collaborative environment and minimize the constraints of conventional methodologies [9]. Historic Building Information Modeling (HBIM) is an effective method for designing conservation projects and managing and documenting invaluable cultural heritage [10]. It can support the project designing, restoration, management, and monitoring of activities at heritage sites through 3D Models and auto-generated orthographic drawings in a systematic manner [7]. Virtual databases can be reviewed using portable devices to develop guidelines for constituting theoretical and methodological frameworks to document architectural heritage accurately [11]. Physical dimensions are based on tangible cultural heritage, and social dimensions are related to non-tangible values. At the same time, time dimensions deal with the scheduling and implementation of conservation projects within the designated time frame [5]. The historic city of Lahore needs a holistic approach to conserving and refurbishing landmark buildings and urban heritage spaces, applying digital tools, methods, and software. The walled city of Lahore functioned as an administrative center during the Mughal Empire (1526-1799). The Mughal Emperor Akbar shifted the capital to Lahore in 1585 A.D. to maintain control in Kabul, and the city also sustained its position as the seat of power during the Sikh Kingdom (1799-1849) [12]. After British annexation, it came under the control of “The East India Company” in 1849 and was added to the British Empire in 1858 [13]. Being the royal seat of the Mughal, Sikh, and British Empire, the historic core of Lahore has a great wealth of historical monuments, urban heritage sites, and archaeological remains which direly need to be conserved and rehabilitated according to the demands of the modern age [14]. Urban conservation concerning the historic city of Lahore has been studied with physical, social, and time dimensions [15]. The Mai Eidaan courtyard, the selected case study, is located on Fort Road, now part of Food Street, with an additional entrance accessible via Nicha/Neewan Chait Ram Road. The courtyard is surrounded by a cluster of residential buildings of high architectural, tourist, and commercial value in terms of original and adaptive reuse. The cluster of buildings around the courtyard comprises an Imam Bargah (a congregation hall for Shia Muslim commemoration ceremonies), two restaurants, some houses, and two residences functioning as shoe factories (Figure 1).

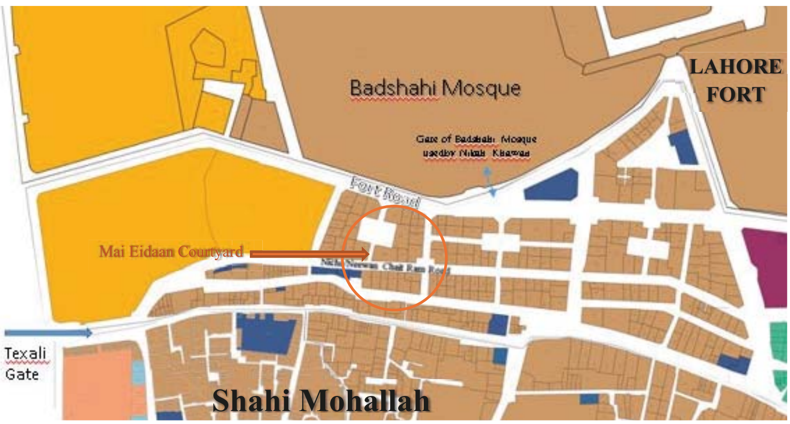


Figure 1. Plan of the Mai Eidaan courtyard with buildings surrounding the courtyard (Basemap WCLA and modified by authors).

It is an example of the historical context; in the historic city of Lahore, there are hundreds of spaces with buildings listed in three categories based on architectural values: high, middle, and low. It has become a challenge for stakeholders to revitalize the historic environment of religious, social, and architectural values. Therefore, it is necessary to schedule conservation projects with digital technologies to revive the urban built heritage environment, focusing on minimizing the restrictions of conventional methods [16]. As a pilot case study in this research, the Mai Eidaan courtyard was selected - due to its location in the historical context and tourist value - for scanning with a terrestrial laser scanner (TLS), and the scanned data was processed to develop an HBIM model through Autodesk Suit (Autodesk Recap 360 and AutoCAD 2016) for surveying, mapping, and documenting, to achieve precision and accuracy, in addition to saving time and human resources. HBIM can provide an integrated platform for stakeholders to share and access building information during conservation projects. HBIM permits multiple team members to use the same model simultaneously, permitting real-time coordination of numerous conservation activities. It can also reduce the probability of errors and rework. HBIM also incorporates metadata to provide comprehensive details about building components, such as the degree of deterioration, previous interventions, maintenance schedule, etc. Metadata in historic building information models can facilitate effective management by providing multilayer information [2].

The research follows the digital mapping of a selected site by using TLS with built-in digital 360 cameras and the development of an HBIM model and auto-generated orthographic details with the help of multiple software, such as Faro Scene 2019, Autodesk Recap 360, and AutoCAD 2016, to achieve a high level of precision and accuracy.

It explores the potential and scope of digital technologies, such as TLS, concerning conservation techniques and practices. The also research contributes to the development of an understanding of digital heritage documentation, management, and monitoring by investigating the constraints of conventional methods and their application in heritage preservation.

2. Literature review

Historic cities are living examples of past human activities and are real connections to records of certain endeavors. For years, historic conservation has faced various challenges in preserving historic monuments and heritage sites due to conflicts of interest between stakeholders [17]. A rigorous process is required to safeguard historic assets from further decay without compromising their authenticity and integrity. Historic conservation is a process of maintaining, managing, and monitoring heritage assets for the sustainable development of historic cities [18]. The process needs appropriate identification of heritage sites, accurate documentation, assessment of damages, and treatment methods, and it can only be done with the help of HBIM approaches [19].

2.1. Conventional v/s virtual methods

Architectural buildings with rich geometric and ornamental details provide multilayer information for future architects and planners to solve issues regarding function and design aesthetics. Documenting historic buildings and urban areas is a critical step in conservation. Conventional methods are generally inaccurate and are often time-consuming, devour human resources, and present the possibility of human error. Visual and pictorial surveys of the site need to be conducted before conservation to record the current status of the historic monument in its context, to make a record of previous interventions, and to develop documentary evidence of conservation procedures applied at the site and, after conservation, to maintain and monitor the life cycle of the conserved sites [20].

Historic cities are losing their heritage assets due to natural agents, human neglect, and new constructions. Conventional recording tools, such as measuring tapes, tachometers, etc., provide various formats for documentation needs. Measured orthographical drawings provide accurate dimensions of the features and open spaces in and around the buildings, with chances of human errors being made due to issues of accessibility and complexity. Perspective drawings represent the buildings appearing to the human eye, presenting realistic spatial depth and proportion. [21]. Photographic records present data about the general outline, quality of light, and appearance of materials. Sketches produce an environment in an artistic format, whereas videos with sound effects are records of a live visit to a place in a 3D context. A physical model shows 3D aspects of a building. Written documentation describes visual representations and unseen data concerning building materials, owners, and constructors [22].

On the contrary, virtual methods (digital) provide more accurate multilayer information than conventional methods (manual workings). An HBIM model of a building based on a digital database can also support the development of a database for CAD drawings, providing metadata such as horizontal and vertical measurements and building materials (color and texture). Digital databases can also be shared globally for analysis, comparison, and discussion, with minimum ambiguities and discrepancies. Architectural plans, elevations, sections, and perspectives can easily be generated from digital databases [23]. In addition, digital databases can provide a base for walkthrough analyses and virtual reality tours. Modern technology is a way forward to more accurate and authentic multilayer digital data and to help reduce the time needed to complete the task [24].

2.2. Digital conservation and the HBIM collaborative environment

The digital conservation of heritage sites and historical monuments using modern 3D measurement technologies has been devised as an efficient and well-organized tool for the purpose of surveying, mapping, and documentation solutions [25]. Conventional methods such as simple manual measurement, tachometry, and photography have been lagging due to their constraints in quality, accuracy, precision, chances of error, and time span [26]. According to current practices, applying Total Station and Terrestrial Laser Scanners is becoming the most commonly used technique because of its comprehensiveness, accuracy, and rapidity. However, Terrestrial Laser Scanning is the most rapid of the digital technologies [27].

The HBIM approach supports various stages in the process of cultural heritage conservation. The first step is the remote collection of survey data using a TLS technique combined with other image-based survey technologies such as digital 360 cameras and photo rectification. Another step is to monitor the behavior of historic environments over time during and after the conservation of architectural heritage [24]. The specific application of HBIM in the area of refurbishment was introduced by Murphy et al. in 2013, who termed it Historic Building Information Modeling for the first time [28]. Afterward, in 2014, Volk et al. identified causes of decay, deterioration modeling (a process of simulating the deterioration of materials and structures over time), uncertainties of building conditions, and incomplete documentation prevailing in existing structures, with the help of HBIM [29]. In 2018, Bruno et al. produced methodological advancements in HBIM in the form of a structured and integrated model as a database of semantic information [25].

The latest progress in the field of HBIM is to raise the transmissibility of multilayer data through the most modern techniques of virtual and augmented reality (VR-AR). These 3D models are based on TLS scanning and image-based survey techniques to digitize and accurately represent the built heritage [26]. The scan-to-BIM process introduces a new paradigm of the complexity of historical monuments and urban-built heritage, as well as its tangible and intangible values in the field of conservation in terms of information contents and knowledge accumulated in the last decades [9]. Currently, these 3D models have themselves become a research tool, allowing non-destructive operations of investigation and analysis to be carried out on buildings, thus facilitating examination of the deterioration of materials, the geometry of their elements, and their conservation state. The 3D reconstruction of surviving objects can then be integrated with what has been damaged through virtual methods, giving a complete virtual image of the building [30].

Autodesk has been considered a comprehensive suite of HBIM software solutions, including Autodesk Revit, AutoCAD Recap 360, AutoCAD Architecture, Navisworks, and others. For the current project, Autodesk Recap 360 and AutoCAD Architecture were selected as they are easy and compatible in terms of measurement of the metadata of buildings, such as height and width, and door and window details, the identification of any damage, their user-friendliness and interoperability, and their ease of sharing with other stakeholders [27].

The application of HBIM for existing structures differs from its use for new projects. Scan data can be converted into AutoCAD & Autodesk Revit files to get accurate and authentic metadata based on 3D models, auto-generated orthographic drawings, and as-built drawings with details of materials and construction techniques [31]. All the processes of digital conservation also help in the adaptive reuse of historic environs to fulfill current community needs.

2.3. Interoperability within different software environments in HBIM a chances of errors

HBIM creates a collaborative environment among historians, architects, engineers and conservation experts, facilitating them to jointly document and preserve historical building metadata such as construction dates, architectural styles, previous modifications, etc. [7]. A collaborative environment enables stakeholders to share their expertise in the digital documentation process, confirming the capture of all relevant information and integration into the HBIM model. In addition, it enables the sharing of information among stakeholders working in different fields, leading to an understanding of historical building materials, construction techniques, and cultural significance [31]. It also provides material specifications, including their composition, age, condition, and provenance, thus supporting conservation efforts and preservation projects [30]. The key support given by HBIM models is briefly described below.

- HBIM platforms are designed to integrate with heritage documentation tools, such as laser scanning, photogrammetry, and 3D modeling software, allowing historical data to be seamlessly incorporated into the BIM model.
- HBIM promotes interoperability with conservation software tools for structural

analysis, material testing, and restoration planning, enabling informed decision-making in heritage conservation projects.
- Interoperability in HBIM facilitates data exchange with cultural institutions and heritage organizations, ensuring that historical building information is shared and preserved for future generations.

TLS is a modern and powerful technology for capturing the 3D data of historic monuments and heritage sites, but similar to any other technology used for measuring, it is also subject to chances of errors in terms of precision and accuracy. These errors can be due to instrument calibration errors, target reflectivity and surface properties, range noise and signal attention, scan registration errors, geometric distortions, point density and sampling errors, data processing, and filtering. By considering these possibilities of error, TLS users can reduce them through careful calibration, data processing, error modeling, quality assessment, and uncertainty estimation techniques.

2.4. Digital documentation within the historic core of Lahore

The historic core of Lahore is comprised of a variety of building types and historic urban open spaces, reflecting a distinctive and comprehensive pattern of spatial development. It was divided into nine districts termed Guzars at the time of Emperor Akbar [32]. They were named after the administrator or the activity being performed in the area. The buildings have been classified under three categories: high, medium, and low [33] by the Walled City Lahore Authority (WCLA), depending on their architectural characteristics and construction period. Patrick Geddes (1854-1932), after a short visit to Lahore in 1917, gave an idea of "conservative surgery" based on the improvement of old buildings and the construction of quarters rather than demolition and reconstruction [34].

It has remained a challenge for the authorities to protect this urban heritage due to the constraints and limitations of conventional tools. New technologies have introduced fast-track and authentic surveying, mapping, and documenting of significant historic buildings. At the same time, a process of accurate preservation has helped to give new life to old structures, as adaptive reuse is not a new phenomenon but a process that started with the development of the built environment [35].

The TLS technique was introduced in Pakistan by Dr. Murtaza Taj from LUMS University, who digitally documented six sites using a Leica Scan Station P20. The selected six sites included Mosque Wazir Khan Lahore, the Temple of Shiva Johi, Daddu, Takhat-e-Bhai Mardan, Darewar Fort Bahawalpur Multan, Mosque Khudad Daddu and stupa at Julian Huripur. Mosque Wazir Khan was digitally documented in collaboration with the Walled City Lahore Authority (WCLA) in 2015 [36]. TLS technology was adopted by the Agha Khan Cultural Services of Pakistan (AKCSP) for the documentation and conservation of built heritage after LUMS and AKCSP completed several successful projects in collaboration with WCLA. The most significant were the Conservation of the Chauburji gateway, the Picture Wall at Lahore Fort, and the Façades of Wazir Khan Mosque [37]. WCLA has identified zones of special value in the walled city of Lahore. Out of these identified zones, Bazaar-e-Hakeema and Jogi Mohallah were documented with TLS in 2016 [38]. As a World Heritage Site, Lahore Fort was also documented with TLS under the umbrella of WCLA [38].

Conservation projects completed from 2015 to the present have encouraged WCLA and the conservation community to adopt modern technologies to overcome the limitations of conventional methods and to apply speedy and accurate documentation within the Walled City of Lahore. According to the information provided by WCLA, the TLS, Faro Focus[s] point cloud owned by WCLA is one of the latest versions from Faro Industries with the combination of a 360 digital camera, helping to expedite the digitizing of cultural heritage of Lahore.

3. Case study: the Mai Eidaan Courtyard

3.1. Location and Context

The site of the case study is accessible from Fort Road and Nicha/Neewan Chait Ram Road, located in the Shahi Mohallah, Lahore, which is now part of Food Street. The selected site, "Mai Eidaan Courtyard," is located in the historical context of Lahore Fort, with religious and commercial activities and comprises a courtyard surrounded by a group of buildings of various typologies. The main access to the site is from Fort Road through a street situated in front of the entrance in the south wall of Badshahi Mosque used by the Nikah Khawan (a person who solemnizes marriages) (Figure 2).

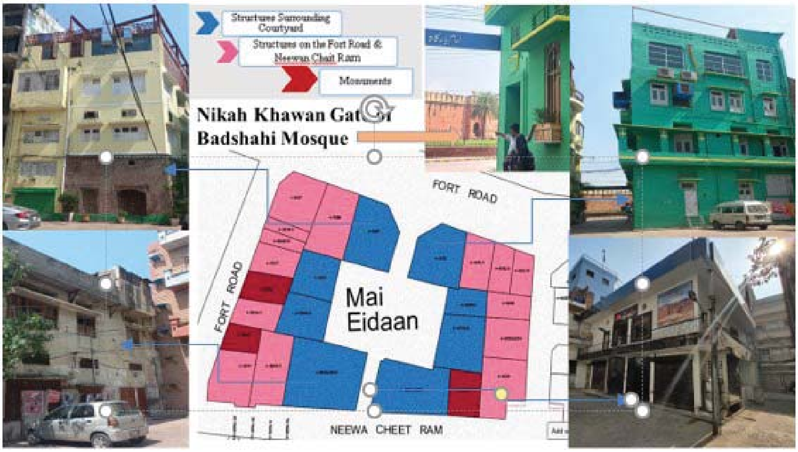


Figure 2. Mai Eidaan courtyard with its context (source: WCLA – modified by author).

In the north, on the entrance street from Fort Road to the courtyard, Andaaz Restaurant is located on the right side, and Royal Dreamland Restaurant is on the left side. These rooftop restaurants present a view of the courtyard of the historical Badshahi Mosque. Mai Eidaan Imam Bargah is situated on the opposite side of the courtyard, in the south, and is accessible from the Nicha/Neewan Chait Ram Road. The first floor of the Imam Bargah serves as a mosque and is used for prayer five times a day by 15 to 20 people of the Shia sect. There are shops on the three sides of Imam Bargah that generate a source of income (such as shop rents) to cover the expenses of the Imam Bargah and Mosque (e.g. salaries, maintenance, etc.). Mai Eidaan was the lady who donated her land for the construction of the Imam Bargah. Her house is situated on the opposite side of the Imam Bargah at the Nicha/Neewan Chait Ram and was recently sold by family members.

The structure on the west side of the Mai Eidaan Imam Bargah is utilized for commercial purposes, for example, there is a shoe factory, as a shoe market is located in the nearby premises. There are, moreover, houses on the east and west sides that have architectural value.

3.2. Historical background

During the reign of Akbar, Lahore was divided into 36 districts (guzars) and 09 of them are in the old city of Lahore. The selected site is located in the Guzar Shehbaz Khan, which is also famous as Guzar Mang Khan and named after Muhammad Shahbaz Khan Kamboh, a Rajput Kamboh was a military general and tutor of Emperor Aurangzeb and famous for his generosity, due to which the area is also called Guzar Mang Khan [32].

Guzar Shahbaz Khan is located in the immediate premises of the southern wall of Badshahi mosque and Lahore Fort and was a place of residence for royal family members, administrators, and nawabs during the Mughal Empire and Sikh Monarch. The area is accessible from the Texali gate from the west, the Masti gate from the North, and the Bhatti gate from the South [12, 39]. The community also used the place and included intellectuals dedicated to pleasing the Royal throne with their performing art skills, such as music and dance [39]. Muhammad Iqbal, Advocate of the High Court and president of Ustad Damon Academy, Texali Gate Lahore, stated in an interview that Chait Ram was a Hindu nobleman famous for his charity to the poor and needy people. The road is dedicated to his name because he used to sit at a place named “Takya of Chait Ram,” located on it, to guide the community in their noble spiritual actions.

Architectural elements of the structures indicate that the area was developed during British rule and occupied by performing artists, musicians, qawwals (a local term for singers), poets, etc. The prostitutes started to reside in this area during the period of Ahmad Shah Abdali, their presence solidified by the British soldiers. One of the shop tenants of Mai Eidaan Imam Bargah said that he had been an eyewitness to all past activities that went on in the area until a ban was called by President Zia ul Haq to crack down on prostitution and to get rid of the “Tawaif” culture. After this ban, most of the prostitutes had to shift to another area to continue their activities, and the vacant houses were purchased by traders, who opened restaurants, factories, and the like. This ban was an initial step towards the commercialization of the Shahi Mohallah. Today, traders and wholesale manufacturers have transformed the residences into commercial places by adaptive reuse. The consequences of this shifting and adaptive reuse of the residences into commercial hubs have enhanced the commercialization of the area. Archaeologists have shown interest in protecting this area to identify its tourist value and to develop it for foreign tourists and visitors [12].

3.3. Architectural and cultural significance

Mai Eidaan was a devotee of the Shia sect. She purchased a piece of land in front of her house, located on the Nicha/Neewan Chait Ram Road, running parallel to Fort Road, and started mourning processions during Moharram (Islamic month in which the grandson of the Holy Prophet Muhammad was martyred), in memory of the martyrdom of Hazrat Imam Hussain. Afterward, an Imam Bargah was constructed in 1954 (as written in the description at the front door of the building). The Mai Eidaan courtyard is sandwiched between some restaurants and the Imam Bargah and is accessible from Fort Road and Nicha/Neewan Chait Ram Road through 15’-0” wide roads. There are shops on the western and southern sides of the Imam Bargah to meet the running expenses of the Imam Bargah and mosque. The administrator of the Imam Bargah rents the shops, which are utilized to pay salaries and the maintenance of the Imam Bargah.

Due to its location and religious activities, the precinct is considered a historic and religious environment. Another function is commercial activity. However, as one of the buildings is utilized as a shoe factory, it damages the historic character of the open spaces. The residents in this area also use this courtyard as a private space for drying clothes in the sun and leisure activities. However, people dining at the rooftop restaurants have beautiful views overlooking the courtyard of Badshahi Mosque.

The courtyard can be accessed through Fort Road, Lahore, which is near the UNESCO World Heritage Site, Lahore Fort. The courtyard is an open space inside Shahi Mohallah, famous for performing arts in past decades. Due to its location in the historical context, it was a favorite place for royal family members, nobles, and royal servants during the Mughal and Sikh Empires, being one of the principal sites for the people who had to attend the Royal court to please the Mughal Emperors with music and dance. Due to its relevance for the royal throne, the area is known as Shahi Mohallah, the residence of people associated with the royal seat [40]. Once upon a time, it was a hub of cultural activities that stopped after Independence. Most of the structures have abandoned their original use and are adaptively being used to fulfill contemporary requirements. As an example, two residences in the Mai Eidaan courtyard have been transformed into restaurants, and two of the residences have adaptively been used as shoe factories, thus accommodating the contemporary needs of the residents.

The group of buildings around this courtyard is comprised of a Mai Eidaan Imam Bargah associated with religious functions, therefore maintaining its original use; two residences have been adaptively reused and transformed into rooftop restaurants, the Andaaz Restaurant and Royal Dreamland restaurant, bearing architectural and tourist value, with beautiful views of the courtyard of Badshahi Mosque; two of the houses have been converted and are now shoe factories with a commercial value; and the remainder of the buildings are used as residences. The Mai Eidaan Imam Bargah reflects the religious environment, especially during the month of Moharram and Safar (Islamic months) for the Moharram proceedings, and the place was dedicated to the memory of the martyrdom of Hazrat Imam Hussain by Mai Eidaan. Initially, it was open land, but after an extended period, a building was constructed on the ground floor, the Imam Bargah, and a mosque on the first floor. Mai Eidaan's residence is on the Nicha/Neewan Chait Ram road, a side road of the Imam Bargah; however, her family members were moved to another part of the city for personal reasons.

3.4. On-site terrestrial laser scanning at Mai Eidaan Courtyard and the HBIM model

The Mai Eidaan courtyard was digitally documented using TLS by a team from WCLA to record and evaluate the operational stages of the TLS surveying, mapping, and processing of scanned data to develop 3D models, which auto-generated 2D measured drawings. The TLS device can survey hundreds and thousands of positions per second. The scanned data is in the form of point cloud data in XYZ format. 3D scanning and producing point cloud data are used to acquire large volumes of accurate data. Conventional surveying methods, such as measuring tapes and digital surveying with theodolite and total station, can never compete with the accuracy and speed of a TLS, which is 976000 points per second in the case of the Faro Focus S70 laser scanner (Figure 3) [28].

Figure 3. The Faro Focus S Laser Scanner shows spheres (targets) and scans surveyed at the site.

For the selected case study, the Mai Eidaan Courtyard, a Faro Terrestrial Laser scanner was used (the Faro Focus is owned by the Walled City Lahore Authority). An architectural plan was drawn up with the help of data collected during the visual and pictorial surveys to fix the target points in the courtyard for the scanning of the facades of the surrounding structures. With the help of "spheres," Artificial Common Reference Objects (targets), four points were fixed to define the range of scanning for the facades.

The scanned data was combined using the Scan Manager of the software Faro Scene 2019 to transform it into a single file. This software gives a 3D model of the scanned site. After converting scanned data into a 3D model, it is possible to delete unwanted elements from the scanned data (Figure 4).

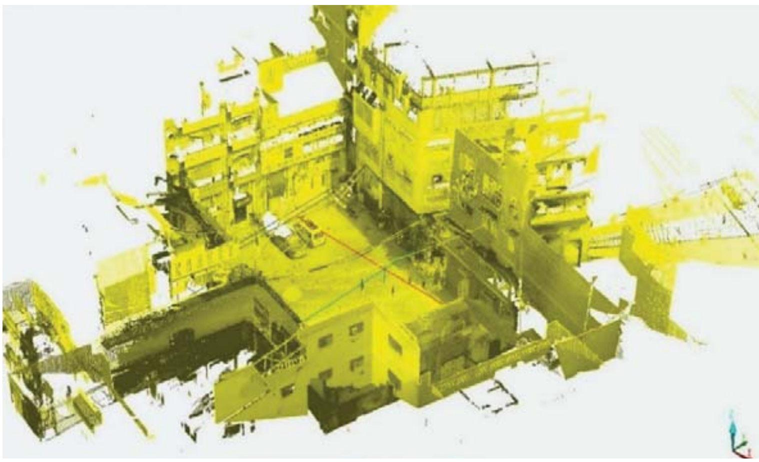


Figure 4. Showing Faro scans of the Mai Eidaan Courtyard

The distance between the target points and objects to be scanned can affect the wavelength of laser beams. Four scans were done with the help of Terrestrial Laser Scanners to cover the facades of the buildings facing the courtyard and the streets linking the courtyard. Each scan is 10 minutes in duration. The target points are shown in Figure 5. The site was scanned with the help of the TLS of Faro S70, and the scanned data was registered with the help of the "Faro Scenes 2019" software. The registered data, in the form of a Recap file, was then transformed into 3D models showing all the details with a high level of accuracy in the minimum time. All the scanning was done in 04 scans, each of 10 minutes, consuming 40 minutes of scanning time and almost 10 minutes for the preparation between the scans. The whole processing from the start of the task till the end was almost 03 hours, after which the file was ready to import into an AutoCAD model to get the multilayer data (Figure 6). The scanned data was combined with the help of Faro Scene 2019 software. The file format is .rcp, and it is ready to export to Autodesk Recap 360 software. These .rcp files can be imported into Autodesk Recap 360 to develop a Building Information Model of the scanned site (Figure 7).

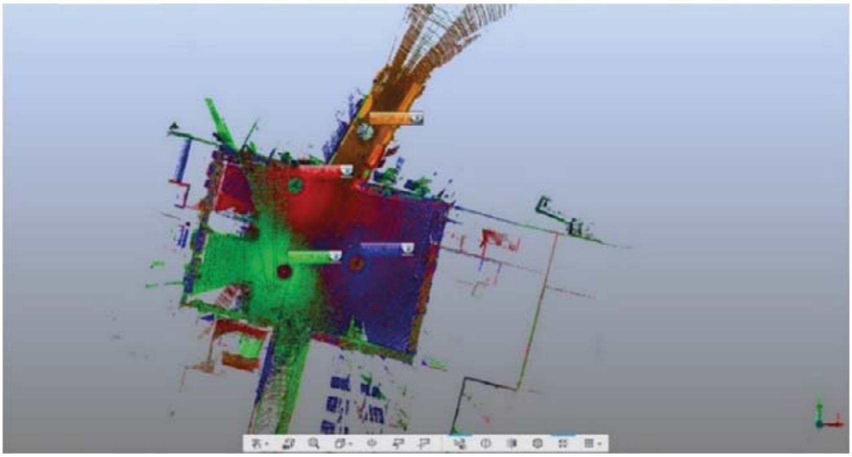


Figure 5. A view from above of the Mai Eidaan Courtyard showing the location of the targets (spheres), using TLS with scenes no.875, 876, 877, and 878.

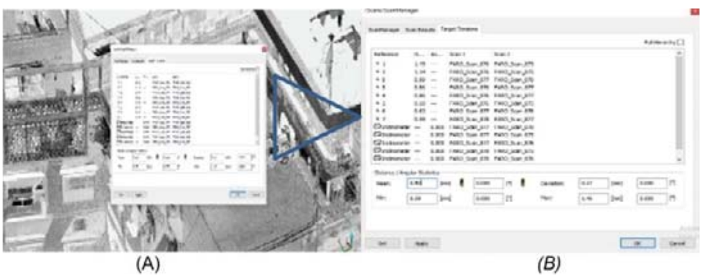


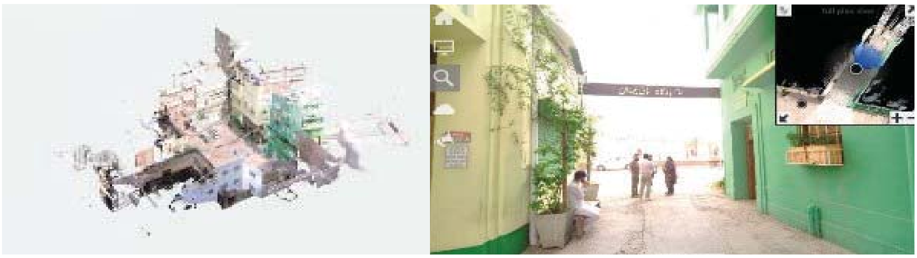
Figure 6. Details of the processing of scanned data in 3D model (Figure A) and details of files (Figure B).

3.5. From scan data to building information modeling

Files edited in “Scenes” in *.rcp format were exported to Autodesk Recap 360 Pro to develop 3D models with multilayer information in RGB colors.

Figure 7. Details showing 3D Models in the Recap support files.

Figure 8A shows a model, while Figure 8B (see upper right-hand corner) shows how the placement and orientation of the targets can be traced to view the desired model. Autodesk Recap can help to develop HBIM models to provide details beyond the limits of conventional methods. The key feature is using the limit box to visualize the details of the facades in the HBIM model (Figure 9A and B).



(A) (B)

Figure 8. RGB 3D model of the selected site (A); and real view of the site in Autodesk Recap 360 (B).

Measurements can also be taken from these HBIM models, saving time and energy. It takes many days to develop measured plans using manual drawings, but HBIM models can be developed, saving time and money (Figure 10 A and B).

In-depth details can be extracted from the HBIM model and can be measured, and the present condition of the deteriorated elements can be recorded with a high level of accuracy and precision for the development of digital models.

(A) (B)

Figure 9. HBIM Model (A) and use of limit box (B).

The HBIM database provides accurate and precise details about the deterioration of materials and causes of decay, as compared to the database of any other conventional technique, such as manual drawings and sketches, photographs, etc. (Figure 11A and B). Building heights are also measured through the expression of colors. Autodesk Recap has the option of obtaining the heights of buildings.

The image in Figure 12 shows the heights at 319-350 meters at a focal length of 50mm. The software can also support "cropping" unwanted objects from the model.

(A) (B)

Figure 10. The HBIM model shows key features for extracting markups (A); and measurements (B).

(A) (B)

Figure 11. HBIM model (A) with extracted details of historic doors of high architectural value (B).

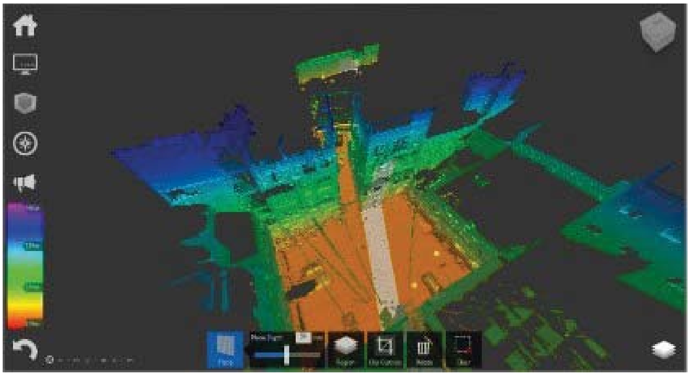


Figure 12. The image captures the building's complete inner view.

3.6. HBIM models in AutoCAD

The files of Autodesk Recap can be opened in AutoCAD and Revit, using an icon to import a point cloud to develop 3D models to execute projects such as as-built drawings and digital documentation of heritage sites [18] (Figure 13).

Figure 13. Elevation of the northern façade of the Mai Eidaan Courtyard.

4. Research methodology

The key objective of the research is to evaluate the potential of scanning and mapping heritage sites and historic buildings using the Faro Focus application (Terrestrial Laser Scanner). It is a valuable tool due to its many merits, including ease of use, chances of error reduction, time and money saving, and the highest quality of work. The environment in which the scanning is done is very significant, as it can influence measurement errors. The temperature difference of 10°C or a change in air pressure of 35 hPa can cause an error of 1mm/100m [41]. With all the benefits, there are a few constraints and limitations regarding applying the Faro Focus scanners at the site. It is pertinent to mention that there is a limitation related to its function in high temperatures as it can impact the wavelength of the laser beam, and, in addition, there are chances of error due to the thermal expansion of the objects being measured. Rain, dampness, moisture, or dusty environments can also influence performance accuracy, and care should be taken to ensure the instrument is protected at all times to avoid accidents (e.g., storing it in congested spaces).

Considering all the constraints and limitations, the site for the case study was carefully selected in a historical context, encompassing various categories of buildings based on their function and architectural characteristics. To ensure the validity of the research, a comprehensive strategy was developed for documenting the selected area, leaving no stone unturned in our pursuit of accurate and reliable data.

- Archival data was collected from the Walled City Lahore Authority and local libraries to identify the site's historical and architectural value and context. From the historical context, it was evaluated that the site's conservation and refurbishment can enhance the courtyard's tourist value, in addition to the additional religious value deriving from the Imam Bargah.
- A visual and pictorial survey with DLSR was conducted to develop an initial inventory of the buildings surrounding the courtyard.
- The present status of the buildings was recorded in terms of age, architectural characteristics, and damage spanning the period of their existence.
- Interviews were conducted with the residents, employees, shopkeepers, and visitors to evaluate previous interventions
- The selected time for scanning at the site was 8 a.m. to avoid human traffic and high temperatures, as the site is outdoors, so the work could be completed before noon. The time span was almost 03 hours. The scan data was saved in a memory card inserted in the scanner (by default). Four scans were captured at various points with the help of spheres, termed targets. The scan data was in the form of high-resolution point cloud data.
- A video was made to maintain a record of the on-site scanning and to evaluate the whole activity.
- After the scanning was completed at the site, the rest of the work was completed at the office workstation. The scanned data, saved on a memory card, was registered to the computer with the software application “Faro Scene 2019.”
- After registration of the scan data in .rcp format, the files were transferred to AutoCAD Architecture 2016 files through Autodesk Recap 360 to provide the opportunity to share the data among stakeholders. This software can support files to measure the site's dimensions, visualize the detailed images, and describe minute details regarding damage and construction materials.
- The 3D models and auto-generated orthographic drawings were prepared to develop conservation and rehabilitation plans for the urban built heritage, maintaining its authenticity and accuracy.
- Finally, the data can be transformed to AutoCAD Architecture and Autodesk Revit to achieve a high level of accuracy in the documented drawings. However, Autodesk Revit requires a high level of proficiency in data acquisition and data management.

5. Results and discussion

Digital technologies play a significant role in the building industry in getting the best resource outcomes regarding accuracy, time, and money. The heritage conservation community is also trying to convert its processes and practices from conventional to digital to preserve historic buildings, urban heritage, and archaeological sites. There are various phases in the conservation process, and documentation is one of the most crucial and substantial parts. Conservation experts are consequently constantly trying to find the most authentic methods to document built heritage with the help of digital tools and software.

The journey of remote sensing for the digital mapping of heritage sites started from a total station to Terrestrial Laser scanning in order to save multilayer data in terms of intrinsic architectural details, in-depth damage valuation, surface deterioration, and structural damage, and it would not have been possible without the application of these digital technologies. The application of Terrestrial Laser Scanning has revolutionized the heritage community through the opportunities it offers to scan urban built heritage in depth. Furthermore, it provides scan data that can be processed to obtain AutoCAD orthographic drawings, Autodesk Revit 3D models, and metadata in terms of how old buildings are, their height and current status, their material deterioration and climatic impact, all data that can be used in the preparation of conservation plans (Figure 14A and B).

(A) *(B)*

Figure 14. Terrestrial laser scanner scanned images using point cloud data (A and B).

The scan data provides accurate data that takes a minimum of time and converts it into AutoCAD and Revit files, which are technical solutions to obtain accurate measured details while drawing horizontal and vertical measurements. The data capture for the courtyard was completed in only three hours, but it can take a couple of weeks if done manually, with chances of human error. Other than human resources to document the facades of the buildings encompassing the courtyard, different equipment is needed for measuring the multistory structures.

However, the orthographic projections and decorations such as kashi kari, mosaic, and engravings cannot be measured. Still, they can be scanned with high-resolution point cloud data, and measured drawings can also be prepared by converting point cloud data into 3D CAD and Revit models. These measured drawings are helpful in project planning and execution at the site. Finally, digital technologies also help to develop a digital archive of projects entertained by various conservation agencies.

In this research, digital tools, methods for their application, and software for converting scan data to Auto CAD files were studied as an integrated approach to exploring the scope and potential of Terrestrial Laser Scanning and HBIM approaches for preserving architectural and urban heritage in Pakistan. Figure 15 shows the recap file processed from scan data illustrating the architectural details of the courtyard which can subsequently help in preparing appropriate conservation plans in the future.

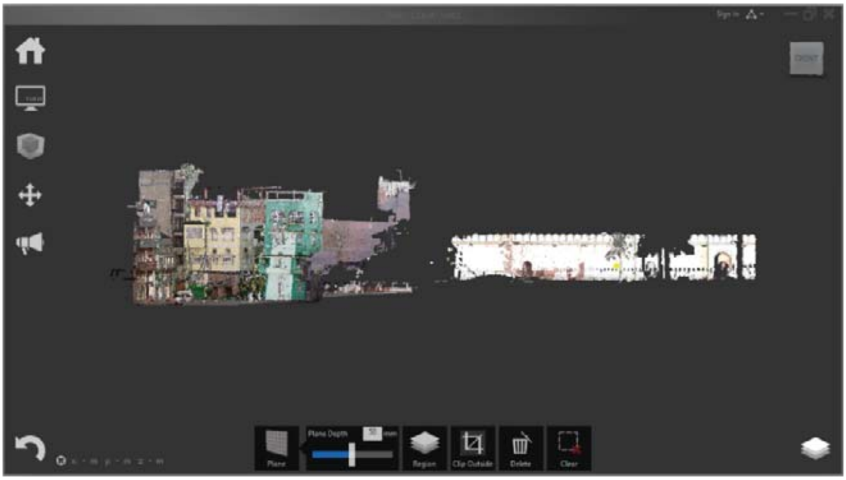


Figure 15. Recap data processed from point cloud data.

The process, once completed in several weeks, can now be done in a few hours at the site, and the work at workstations can also be done in the shortest time with maximum details. Although there are possibilities of errors, they can be minimized through accurate measuring and experience in diverse skills. There is a big challenge regarding the cost of the equipment, but it can be justified based on the number of projects and the type of heritage sites in Pakistan.

The scan data can provide in-depth structural and surface damage details and help manage and monitor heritage sites. Equally, it can be used to prepare a digital archive that is usable for future projects, with data that can be utilized for the sustainable development of historic cities to protect and save the heritage of Pakistan.

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Summary

This study uses a Terrestrial Laser Scanner (TLS), focusing on the Mai Eidaan Courtyard in Lahore, Pakistan, to present a systematic approach to digitally documenting historical monuments and urban built heritage. The architectural and urban heritage is facing accumulative pressure regarding the sustainable development of historic cities. The preservation of cultural heritage is becoming an urgent task for the conservation community if it wants to ensure it survives for generations. The case study is located in the historic center of Lahore. It comprises great historical value, serving as a noteworthy example of adaptive reuse within a historical context and attracting high tourist interest. Using a systematic methodology, this study evaluates the efficacy of TLS in documenting intricate architectural details and spatial characteristics, thereby contributing to the broader discourse on digital preservation strategies for historic urban environments. The methodology integrates terrestrial laser scanning (TLS) as an emerging remote survey data collection tool for mapping systems and documenting the monuments. Heritage documentation and virtual modeling play crucial roles in identifying, protecting, and preserving historic structures, enabling monitoring and maintenance, and providing multi-layered information necessary for conservation efforts. Overall, this research aims to bridge gaps in the literature on digital heritage documentation and highlights the significance of interdisciplinary collaboration for safeguarding urban-built heritage for future generations.

Riassunto

Questo studio propone un approccio sistematico dedicato alla documentazione digitale dei monumenti storici e del patrimonio costruito urbano utilizzando tecnologie basate su Laser Scanner Terrestre (TLS). In particolare, si presenta il caso di studio del Cortile Mai Eidaan. Ad oggi, il patrimonio architettonico e urbano si trova ad affrontare pressioni continue e cumulative dovute allo sviluppo sostenibile delle città storiche. La conservazione del patrimonio culturale è un'esigenza per la comunità e garantisce benefici per le generazioni future. Il caso di studio si trova nel centro storico di Lahore e comprende un gruppo di edifici di significativo valore religioso, commerciale e storico, che costituiscono un virtuoso esempio di riutilizzo adattivo di un contesto storico, inoltre attirano un elevato interesse turistico. La metodologia proposta in questo studio permette di valutare l'efficacia delle scansioni TLS al fine di documentare dettagli architettonici complessi e caratteristiche spaziali, contribuendo così al discorso più ampio sulle strategie di conservazione digitale per ambienti storici urbani. La metodologia integra l'uso della TLS come strumento di raccolta dati da remoto al fine di produrre una mappatura e la relativa documentazione per i monumenti storici analizzati. La documentazione e la modellazione virtuale svolgono un ruolo cruciale nell'identificazione, protezione e conservazione delle strutture storiche, consentendone il monitoraggio, la manutenzione, fornendo le informazioni multilivello necessarie per gli sforzi di conservazione. Nel complesso, questa ricerca mira a colmare le lacune nella letteratura internazionale in merito alla documentazione del patrimonio digitale ed evidenzia l'importanza della collaborazione interdisciplinare per la salvaguardia del patrimonio urbano costruito per le generazioni future.