The Evaluation of the Wooden Structural System in Hijazi Heritage Building via Heritage BIM

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Abstract. The historic district of Jeddah city has a unique traditional building structural system known as the Hijazi style. The structure system of historic Jeddah buildings is based on load-bearing walls and through a unique horizontal load distribution wooden system known as the "Tkalil" system. Moreover, exact identification of this Hijazi building style deficiency necessitates information besides familiarity through the original structural system, as well as the construction method of the Hijazi building style. This can be combined through an advanced scientific method for exploration. This paper will focus on evaluating the Tkalil structural system based on 3D laser scanning and Heritage Building Information Modelling (HBIM) techniques, through different case studies of the historical building in historic Jeddah, Saudi Arabia. Furthermore, the traditional construction technique for historic buildings in historic is multiple-leaf coral-stone masonry load-bearing walls. Moreover, there are several structural deficiencies patterns in these heritage walls which can lead to instability of these heritage buildings structures, as well as the degradation of the structural condition of these heritage buildings' foundations, as well as the flat timber ceilings. Indeed, using advanced techniques for data acquisition (Photogrammetry and 3D laser scanning), then analysing these data via the BIM platform can help to understand the core issues of these heritage buildings before applying any solutions. The 3D laser scanning will provide very detailed and accurate 3D point cloud models. These models will be the base for the heritage BIM models to be evaluated and to indicate the stability of these heritage structural systems.

Keywords: Hijazi · HBIM · 3D Laser Scanning · Jeddah · Wooden Structural

1 Introduction

1.1 The Architectural Characteristics of Hijazi Region

Over the years Hijazi architecture has developed and shown its identity all over the region. The historical houses in Jeddah have unique architectural characteristics which make it a rich source of information for architects, structural engineers, artists, and people who are interested in heritage buildings. The architectural characteristics are not only used for structural or aesthetical reasons, but it can be used for many different reasons

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such as coping with the climatic changes and challenges and dictated by the geographical location and availability of resources in the region. As a result, there are different architectural characteristics that serve different needs such as the Roshan, Mashrabiyah, Manjur Pattern and Plaster decoration. Moreover, according to Ragette (2003), "these historical houses have remarkable and simple design and architecture that represent a rich heritage, demonstrating how local craftsmen and builders adapted designs to respond to social demands and other environmental factors in earlier periods". As a consequence of this evolution, the old houses designs have a unique pattern, as well as being authentic and functional. Moreover, the uniqueness of pattern takes a turn for the better in reducing humidity and increasing thermal comfort, as the buildings increase cross ventilation (Eleish 2009). According to SCTA (2013), the historical houses of Jeddah have to be "understood as an urban unit active in the making of the city", therefore these houses need to be "studied as typo-morphological responses to climate, material and socio-spatial practices". By focusing on the Roshan, it can be found that it is the basic and primary urban unit of the historic Jeddah houses. These Roshans had a significant role in the shaping of the urban fabric, which was originally comprised of tightly knit areas integrating commercial, residential functions, and organised around the main market and the social identity of the historical city. Furthermore, SCTA (2013), pointed out, "Through its programmatic, climatic, spatial and visual characteristics, it contributed to the shaping of the urban morphology, land use patterns and the overall character of Jeddah". In recent years, the historical houses have been used as multi-purpose buildings that house residential and commercial activities. Additionally, the historical houses are private spaces that equal to the street level and connected with semi-private spaces such as offices, markets, warehouses. Also, it could be used as hotels during the season of Al-Hajj. Jeddah historic houses are designed effectively to meet the considerations of climate challenges. As a result, historical Jeddah houses are very efficient and critical in shaping the morphology and the urban fabric of the historic city. In addition, the orientation of the street network of the historic city is designed to correspond to the prevailing breezes, north and northwest to make the pedestrian movement more comfortable. Furthermore, the impact of the shade and light, the alternation of cool and warm surfaces, and hot and cool spaces is clearly allowing the airflow of the city. In general, the Hijazi historical houses, could be described as individual or semi-individual units in a humid and hot area. As a result, it creates larger street network and increases the air flow and cross ventilation. The distribution and dimension of the historical Jeddah houses are important elements to keep the streets protected from heat and sunrays and keep it in the shade. Moreover, the houses are distributed according to their heights, the high houses are used as "wind catchers" to allow the breeze that comes from the sea to maintain continuous vertical air circulation inside the houses, based on the natural upward movement of hot air across stairwells and shafts, pulling air over the windows (Roshan and Mashrabiyah), which in turn cools the inside and favours air circulation. An important architectural solution for dealing with Jeddah's climate is "Al-Mabit in Arabic", which was used for sleeping during the summer nights; it was normally built from panelled wood with louvers and a light roof (Fig. 1).

Moreover, Al-Lyaly (1990) defines it as, "Al-Mabit on the uppermost floor is like an air pavilion", furthermore, "The louvered timber walls surrounding it on two or

(a)  (b)

Fig. 1. (a) The dense fabric of the old city **(b)** Example of the Roshan

sometimes three sides allow the air to circulate freely in the space and at body level thus enhancing the comfort of the occupants". The most common architectural characteristics in historical Jeddah are the Roshan and Mashrabiyah, which create a rich and distinct visual character for the old Jeddah city. Further, both Roshan and Mashrabiyah play an important part in different ways, such as allowing for cross ventilation, water-cooling, views, and decoration, and offering privacy. The next part will explain more about Roshan and Mashrabiyah.

Roshan and Mashrabiyah. Roshan and Mashrabiyah; "wooden bay windows" are the most striking of Jeddah's historic houses, but these architectural features are also common in many Middle Eastern Islamic cities such as Istanbul, Damascus, Cairo, Baghdad, and Suakin. Moreover, in historic Jeddah, both Roshan and Mashrabiyah are unique for many reasons. For example, these features are connected from floor to floor, are larger in size, more diverse in sculptural techniques and decorations, and contain a mix of different elements. Influences from Asia and India (SCTA 2013). Additionally, due to the diversity of the population and the multicultural influence of visiting artisans and artisans, these influences are reflected in the Roshan and Mashrabiyah variations in historic Jeddah. The taste and wealth of the owner influenced the quality, size, and decorative design of these Roshans and Mashrabiyah. Roshans and Mashrabiyah were created in different sizes and styles. In some buildings in Historic Jeddah, the entire facade is covered with a large Roshan. The Roshan, on the other hand, can have the usual width, four or five bays, but the span over two or more floors of the house (multi-storey), or even the entire height of the building. Roshan and Mashrabiyah, can be connected vertically, connecting the top of one to the base of the other with wooden strips, or horizontally, joining the caps together into a single hat stretched across many Roshans and the spaces between them. Next to Roshan or Mashrabiyah, inside, there is usually a flat platform "30 to 50 cm high"; this platform is used to sit during the day and sleep at night (SCTA, 2013).

Manjur Pattern. The Manjur pattern can be defined as a lattice grille of wood or a shish net, always in the upper part of Roshan or Mashrabiyah. The main purpose of Manjur is to catch soft light and maintain shade, besides, to catch a cool breeze, which is desirable in the hot climate of Jeddah. Culturally, the Manjur provided a veil, allowing families inside the house to look outside without being seen (A. Baik & Boehm, 2017). The idea of Manjur's beautiful designs is to have specially cut wooden slats interlocking at right angles (criss-crossed) and housed in a frame. These Manjur designs provide a pleasing look from the outside as well as the inside. The shape in which the edges of the laths are cut determines the shape of the gaps created between the two laths, as well as the complete style of the Manjur net (A. H. Baik, 2020).The Shish (wooden net) usually contains two or more shapes arranged in sequence to give the Manjur the desired form, and in general, the size and shape of the Manjur pattern are chosen to give the Manjur the desired pattern, and a balanced combination of shade, delicate light, pleasant breeze, and privacy (A. Baik et al., 2014).

Gates and Doors. Another important architectural characteristic in the historic city of Jeddah is the gates, both internal and external. In addition, these wooden gates have compound leaves and are decorated with carved panels depicting some of the finest woodwork and ornamentation in Arabia. The main entrance gate receives considerable attention in traditional buildings in Jeddah. Regarding the design of these gates, it can be noticed that these gates are quite tall, have rich decorative panels, and carved patterns on both sides, and are framed with carved stone or decorative plaster. Moreover, these designs appear as repeated floral as well as asterisk motifs connected by geometric patterns and/or polygonal polygons or pointed stars. In addition, it can be noted that in some parts of the gate its carved patterns are shallower and deeper than in others.

Plaster Decoration. As a result of the humid and salty weather in Jeddah, the limestone and coral blocks were affected. The main solution to protect the walls and surfaces of these buildings is the use of the plaster. Over time, plaster craft improved and developed, resulting in decorative plaster sculptures on the facade. As can be easily seen, decorative plaster is always concentrated on the ground floor of facades, especially around windows and main gates of the buildings in historic Jeddah. Regarding the plastering and decorating process, the work is applied to the coral walls while they are still wet. The beauty of plaster decoration lies in the contrast between carved and uncarved surfaces, creating a difference in shadow and shadow. Excellent examples of carved plaster decoration can be found in the historic house of Jokhdar and Ribat al-Khonji. Although there is no scientific study of the plaster decorations in the historic city of Jeddah, it seems that the old decorations were simpler and more geometric, while the plaster one's Later carvings became more complex with intricate decorative patterns being carved more deeply into plaster and remaining in its thickness. An interesting aspect that has been found in some of the main facades of buildings in the historic city of Jeddah is the sgraffito. Sgraffito is always located on the ground floor corner of the two facades and this sgraffito was created by scraping a surface to reveal the contrasting colour underneath. These sgraffiti are usually in the form of rectangular or square slabs; otherwise, they are rarely available in relief form as on the Nasif Historic House (Fig. 2).

Hijazi Structural Technique (Takalee). The Hijazi houses are considered one of the types of evidence of creativity in the Hijazi heritage architecture, as they stand for hundreds of years. Each part and detail contain many lessons and concepts. There is no pointless part in it, there is a reason behind every detail. As a result, it is built arbitrarily in the Hijaz heritage architecture, either to prove a right or to improve behaviour. During

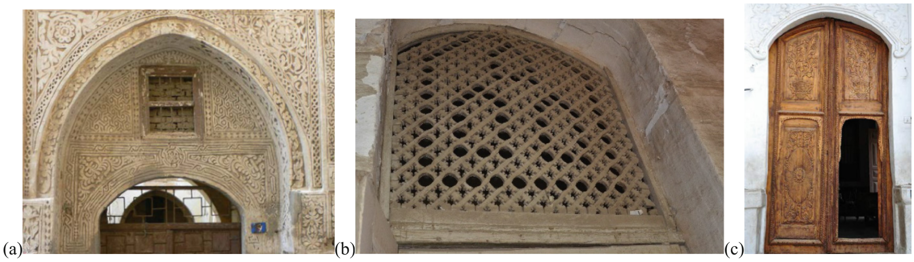

Fig. 2. (a) Decorated doorways (b) Manjurs in Jeddah houses (c) An example of the wooden doors in Jeddah.

the past years, there are many travellers and tourists who record their fascination with Hijaz heritage architecture by describing the height of its buildings. The observations of most of the travellers who passed through Jeddah cantered on three main points: that it is a clean city, and its people are suffering from a lack of access to clean water. Moreover, many travellers described its buildings as one of the tallest buildings at that time. The buildings reach a height of about 30 m which was not usual 500 years ago. As a result, how could the people of Jeddah with their simple capabilities and limited resources construct buildings that reach a height of seven and eight floors. Especially it is constructed with coral rocks extracted from the sea in the form of large pieces and then cut into smaller pieces as needed (which is considered as one of the non-solid stones and according to its physical components, it cannot bear more than two floors only). This came by using some special construction techniques such as (Takleh or Takaleel) which is a frame made of solid wood; builders used to put it horizontally at specific heights (usually 1m) to increase the stability of the building leading to having a greater number of the floors and increase the height of the building. These Takleh have main six uses first, it is a very important structural element that helps in transferring the loads horizontally, rather than vertically nature. Thus, the entire wall supports and cooperates with each other to bear the loads above it, the strong stone is supported by the weak stone. Therefore, the capacity of these stones' doubles, and they can bear more with having the Takleh. Besides, the other techniques such as the thickness of the walls, the method of their construction, and emptying the walls as much as possible from the inside and outside…etc. The second use of Takleh lies in holding other building elements such as doors, windows, beams, etc. The coral rock is fragile and full of voids and cavities, and it cannot hold anything on it, so Takleh were used for having more stabilization, especially since they are made of the hardest wood. The third use of Takleh is measuring the level of the building. Builders used to place Takleh at close and specific heights between 70 cm to 100 cm approximately, and it helps to hide the differences in the building or between the sizes of the excavated stones, which were formed manually. As a result, the builders ensure that the heights of the building from all sides are equal. Fourth, the Takleh is used to inspect the apparent safety of the buildings, if there is any bending in the Takleh that means the loads are not distributed properly and the building needs maintenance. Fifthly, the Takleh is the most important element to be used during maintenance, as the builder suspends the building over the damaged part (the part that needs repair) by placing strong supports of wood under the overlay which maintenance is required, and then the wall under that overlay is removed and rebuilt. This is an advantage that you will not be found in any other house. The Hijazi house could be destroyed and rebuilt again, which helps to facilitate maintenance work and increase the life span of the Hijazi buildings, as many buildings are more than 500 years old. Finally, these Takleh are considered an aesthetic element in the Hijaz buildings, their horizontal extension breaks the sharpness of the vertical height of the buildings and makes it more acceptable to the human eye. Therefore, the builders, when they finish the buildings from the outside do not cover the Takleh, but they highlight them in a striking way, so people can enjoy their beauty. However, the invention of Takleh by the ancient builders is considered one of the greatest inventions that have had a significant impact on architecture in the Hijazi region (Figs. 3 and 4).

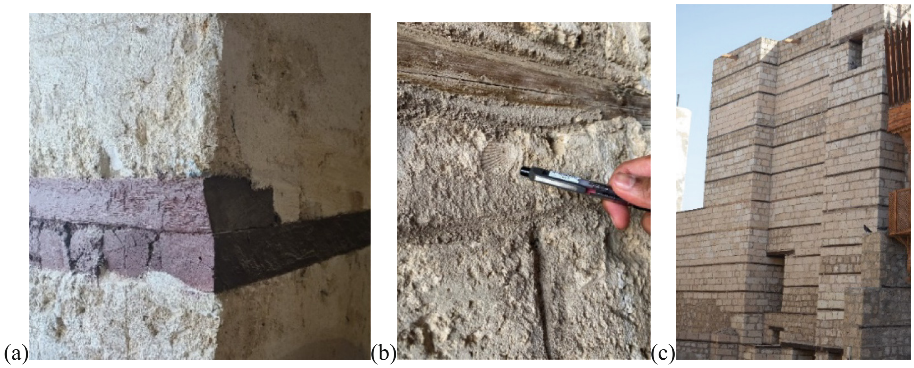

Fig. 3. (a) Takalee on the interior facades (b) Mangabi stone. (c) Takalee on the facade

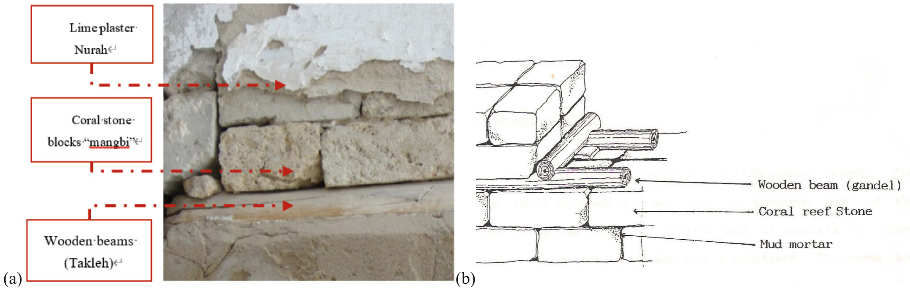

Fig. 4. (a) This image illustrates the construction materials used in building Red Sea houses. (b) Wall construction details (Source: Alharbi, 1989, p.241)

2 3D Reality Capture Technique in Heritage

The 3D reality capture techniques are methods used to capture detailed 3D data of a heritage building or structure, which can be used to create digital representations of the heritage building. These techniques include:

- Laser scanning: This method involves using a laser scanner in order to capture detailed 3D data of the building's surface geometry, including its walls, roof, windows, and other features. The scanner emits a laser beam that reflects off the building's surfaces, and the scanner's sensor captures the reflection and records the distance from the scanner to each point on the building's surface (A. H. Baik 2020).
- Photogrammetry: This method involves taking photographs of the building from different angles and using software to process the images and create a 3D model of the building's surfaces. This can be done using a camera mounted on a drone or a ground-based camera (Alshawabkeh et al. 2021).
- Structure from Motion (SfM): This method uses a series of overlapping photographs taken from different viewpoints to generate a 3D model of the building or structure (A. H. Baik 2020).

Once the data has been captured, it can be used to create detailed engineering drawings, maps, and other visualizations of the building's structure, including its geometry, dimensions, and surface details. This data can be used to identify potential issues, such as cracks, deformations, or damage, that might not be visible during a visual inspection. It can also be used to create a digital twin of the structure, which can be used for ongoing monitoring and analysis, and to simulate different scenarios in order to help with the decision-making procedure(A. H. Baik 2020).

2.1 Terrestrial Laser Scanning "TLS"

Terrestrial laser scanning is an automated measurement technique that measures the surface 3D coordinates of a selected object. Laser scan output data is displayed in point cloud format. Each of these points has x, y, and z coordinates of the scanned surface. Furthermore, several laser scanning systems are available on the engineering market today. However, these systems have three types of scanners methods. These can be suitable for metric heritage studies: (time-of-flight) scanners, triangulation, and phase comparison (Murphy 2013). Additionally, the difference between these scanners systems has to do with how the scanner calculates 3D coordinate measurements. For example, for the triangulation type, the scanner uses laser beam points on the surface of the object captured with one or more cameras (A. Baik 2016). Alternatively, according to Boehler et al. (2003) "time of flight scanners calculate the range, or distance, from the time taken for a laser pulse to travel from its source to an object and be reflected back to a receiving detector".

2.2 Terrestrial Laser Scanning Data Processing

Laser scanning captures a variety of data representing 3D coordinates known as "point cloud data". These point cloud date need a professional program in order to deal with the huge amount of data. Moreover, usually capturing millions of accurate 3D points could take a few minutes, on the other hand, there is enormous work in transporting this point cloud data into a 3D model which containing useable information (Baik et al. 2014). Moreover, there are several programs in the market which can deal with the point cloud date. For examples, Leica Cloud-Works, Polyworks, Autodesk ReCap and RiScanpro which have greatly improved the processing, manipulation and analysis of vector and image data from point clouds. Also, these software platforms are combined algorithms for triangulation and point cloud surfacing (Remondino 2003). After the scanner point cloud has been transferred, there are a number of suitable software programs that can be dealt with troubleshoot and remove the noise or the point cloud distortion from the scanner data. In addition, each system of these laser scanners has its own software package. For example, Leica Cyclone® carries the Leica laser scanning system. Overall, the Leica Cyclone® modelling approach is to generate an optimally shaped object from a point cloud data. Additionally, the Leica Cyclone® has several object-specific utilities that the user can select according to the topology of the scanned point cloud (A. Baik et al. 2013). On the other hand, other software programs are applied instead of polygonal 3D models; NURBS surface models, or editable feature-based CAD models (Ikeuchi 2001) (Fig. 5).

(a) (b)

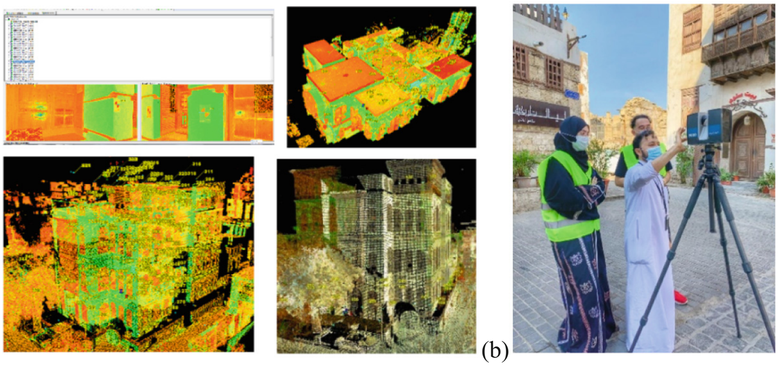

Fig. 5. (a) Point Cloud Data processing. (b) Using laser scanning

2.3 Combining Laser Scanning and Digital Images

Most modern laser scanning systems have a built-in camera for image data. Additionally, 3D point clouds can be coloured by applying stacks of multiple images to the point cloud data. RGB colour data from an image can be mapped to range data taking into account point translation, instrument rotation and perspective projection (Abmayr et al. 2005).

This requires geometrically correct calibration of both the laser and the camera as well as the Camera corrections are presented to correct for camera lens distortion, and via mapping to a point cloud, the image Viewpoints contained in are removed (Murphy 2013). Furthermore, a High Dynamic Range "HDR" colour image can be accurately mapped onto a geometric model represented via the point cloud if the position as well as the orientation of the camera in the coordinate system of the geometric model is known (Beraldin 2004).

2.4 Heritage BIM

HBIM stands for "Heritage Building Information Modelling." It is a process of creating a digital representation of a Heritage building or structure using Building Information Modelling (BIM) technology and tools. This representation can include information about the heritage building's architecture, construction, materials, and history, as well as data on its current condition and maintenance needs. Heritage BIM can be used in order to aid in the preservation and restoration of heritage buildings, as well as in their ongoing management and use (A. Baik et al. 2013). Moreover, Heritage BIM is an interactive solution representing interactive engineering 3D model. Usually, this 3D model is based on terrestrial laser scanning data "TLS", Architectural photogrammetry, and culture heritage data (A. Baik et al. 2014). In addition, Heritage BIM automatically provides complete technical drawings, orthographic views, sections, and 3D models. Regarding the Heritage Conservation and Preservation sectors in Historic Jeddah, Heritage BIM can support in several aspects, such as improve the understanding of heritage buildings and the context, Knowledge of the building materials, construction as well as the structural techniques, and the building pathologies, understanding the heritage building materials (A. H. Baik 2020). The field of heritage conservation will also benefit from Heritage BIM in a variety of ways, including by enabling a thorough analysis of proposed renovations and changes before final decisions are made, assisting with the heritage building maintenance, helping with budgeting for repairs and maintenance, and enabling a wider public building experience because models can be viewed using free viewer application from remote locations (A. Baik et al. 2013). Furthermore, the opportunity to develop details about the object's methods of construction and material makeup is also provided by introducing the culture heritage information of Jeddah and the Hijazi region. Through the use of various program platform management techniques, the prototypes of the libraries of parametric objects are modelled onto the photogrammetry as well as the point cloud data during the Heritage BIM process (A. H. Baik 2020) (Fig. 6).

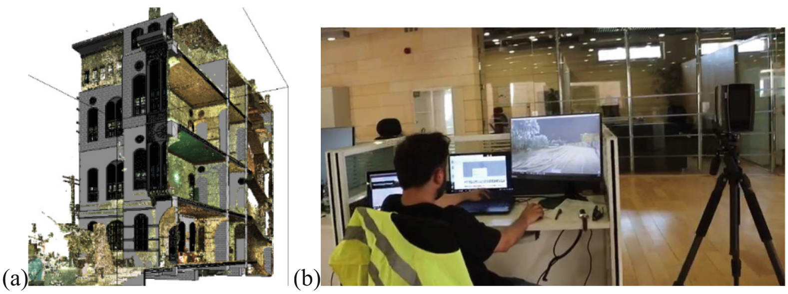

Fig. 6. (a) HBIM model for Nasif House (A. H. Baik 2020) (b) Combining the laser data with the photogrammetry

3 The Evaluation of the Wooden Structural System (the Method)

3.1 Visual Inspections

Visual inspection for heritage structures is an important aspect of their preservation and maintenance. These inspections involve a thorough examination of the heritage building's exterior and interior, including its roof, walls, windows, doors, and other structural elements. Usually, during the visual inspection, an inspector will look for signs of wear and tear, damage, or deterioration, as well as any potential safety hazards. They may also take photographs or make notes to document their findings. Furthermore, The inspector may also use specialized tools and equipment, such as binoculars, ladders, scaffolding, or drones, to access hard-to-reach areas of the structure (Van Balen and Verstrynge 2016). Moreover, the results of the visual inspection can be used to identify potential issues that need to be addressed, and to develop a plan for preservation and maintenance. This can include repairs, restoration, or conservation work, as well as ongoing monitoring and maintenance to ensure the building's continued stability and integrity. In the case of this paper, the first step was to be coding the building elevations. Then taking pictures and ortho pictures for these elevations, celling, and floors. And determine the damages. This step is very important to produce any 2D as-built CAD drawings from both laser scanning and the visual inspections. Then, drawing this elevation in 2D CAD drawings. These drawings will contain the as-built condition with all damages (Fig. 7).

Fig. 7. Visual inspections, coding and taking pictures for the elevations.

3.2 Terrestrial Laser Scanning Phase

Laser scanning is a technology that can be used for structure evaluation of heritage buildings and structures. It involves using a laser scanner to capture detailed 3D data of the building's surface geometry, including its walls, roof, windows, and other features. The scanner emits a laser beam that reflects off the building's surfaces, and the scanner's sensor captures the reflection and records the distance from the scanner to each point on the building's surface. This process is repeated many times to capture a large number of data points, creating a detailed 3D model of the building (Schueremans and Van Genechten 2009). Furthermore, Once the data has been captured, it can be used to create detailed drawings, maps, and other visualizations of the building's structure, including its geometry, dimensions, and surface details. This data can be used to identify potential issues, such as cracks, deformations, or damage, that might not be visible during a visual inspection. Moreover, The data can also be used to create a digital twin of the structure, which can be used for ongoing monitoring and analysis, and to simulate different scenarios to help with the decision-making process (Cuartero et al. 2019). In the case of this paper, it was very important to use the laser scanning to document the as-built condition in 3D digital environment. The first step was to get the georeferenced coordinates of the buildings. The second step was to plan for this phase and to determine the best locations for both the laser scanning spots and the black and white (B/W) targets. The third step was to scan the buildings from outside to inside the buildings. The fourth step was to process the point cloud data to be registered and include all laser scanning spots (both outside and inside scans). The final step was to paper the data to be use for Heritage BIM process. It is very important to emphasize that the outcomes of laser scanning phase are very important to be used in processing the 2D as-built CAD drawings. That is because of the high accuracy and accurate measurements that laser scanning provides (Figs. 8 and 9).

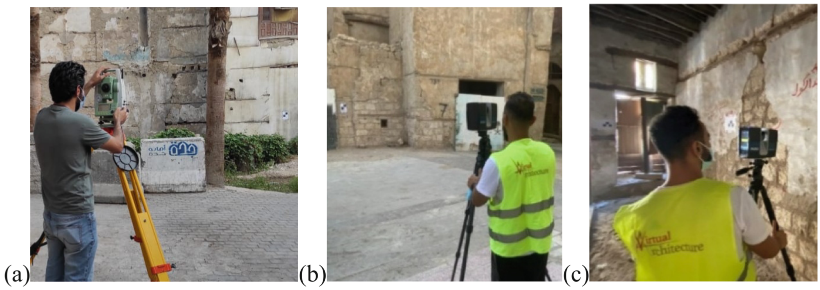

Fig. 8. (a) georeferencing the targets (b) canning the building's facades (c) Scanning the building from inside

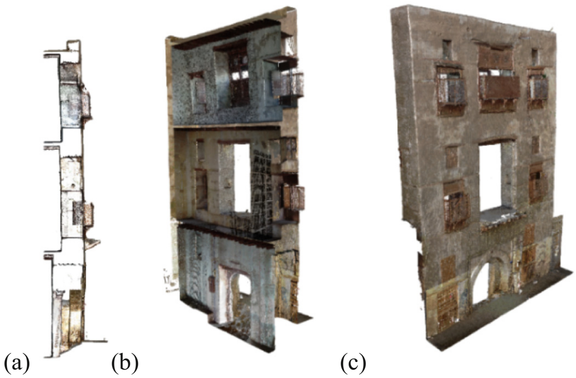

Fig. 9. (a) the exterior façade of case 1 (b) the interior façade of case 1 (c) Section

3.3 HBIM for Structure Simulation

Heritage BIM can be used for structure simulation of heritage buildings and structures. Furthermore, once the HBIM model has been created, it can be used to simulate different scenarios, such as load-bearing capacity, structural behavior, and environmental effects, on the building's structure (A. Baik et al. 2013). This can help to identify potential issues and to develop a plan for preservation and maintenance. For example, the HBIM model can be used to simulate the effects of different loads, such as wind, snow, or earthquakes, on the building's structure. This can help to identify potential weak points or areas of the building that may be at risk of failure. Additionally, the HBIM model can be used to simulate the effects of different conservation and restoration treatments, such as the addition of new structural elements or the removal of old ones, on the building's structural integrity (A. H. Baik 2020). Furthermore, Heritage BIM can also be used to model the building's environmental behavior and energy consumption, which can be used to improve building's performance. It can also be used to create virtual tours, which can be used for education, awareness and for the promotion of the heritage building. In the case of this paper, the heritage BIM modelling was built based on the 3D point cloud data. In these steps it was very important to identify the LoD for both information (iLoD) and elements (eLoD). The second step was to prepare the model for different engineering simulations, for example, structural, environmental, MEP and many more (Figs. 10 and 11).

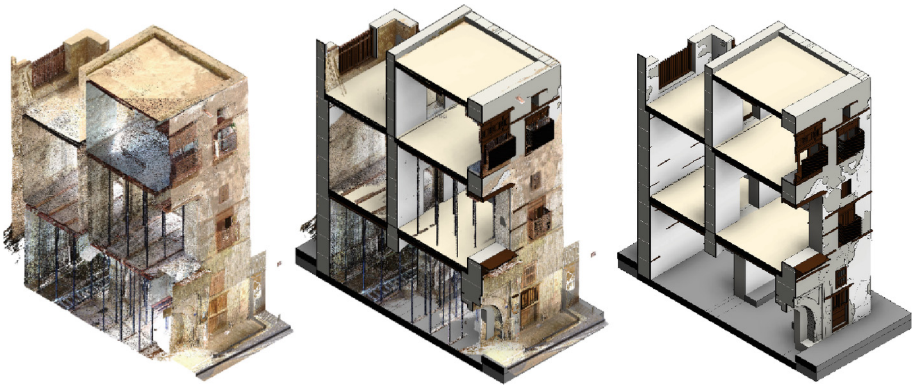

Fig. 10. The vertical section shows the HBIM modelling process

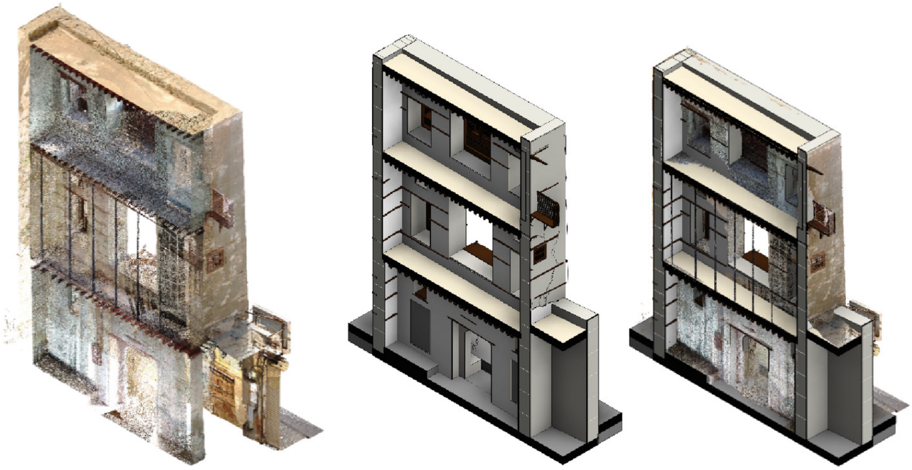

Fig. 11. Section shows the interior façade in BIM modelling process.

4 Conclusions

The evaluation of the wooden structural system in Hijazi heritage buildings using Heritage BIM is an important aspect of preservation and conservation efforts for these buildings. Hijazi heritage buildings are a type of traditional architecture found in the Hijaz region of Saudi Arabia, and they often feature wooden structural systems that are unique and complex. Using Heritage BIM, a detailed digital representation of the building can be created, which includes information on the building's architecture, construction, materials, and history, as well as data on its current condition and maintenance needs. This model can be used to simulate different scenarios, such as load-bearing capacity, structural behavior, and environmental effects, on the building's wooden structural system. For example, the Heritage BIM model can be used to simulate the effects of different loads, such as wind, snow, or earthquakes, on the building's wooden structural system. This can help to identify potential weak points or areas of the building that may be at risk of failure. Additionally, the Heritage BIM model can be used to simulate the effects of different conservation and restoration treatments, such as the addition of new structural elements or the removal of old ones, on the building's structural integrity. The Heritage BIM model can also be used to evaluate the building's environmental behavior and energy consumption, which can be used to improve the building's performance.

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