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From point cloud to Jeddah Heritage BIM Nasif Historical House – case study

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ABSTRACT

The heritage buildings in historic Jeddah City face serious issues related to their management, conservation, documentation and monitoring of this important building sector. In recent years, incorporation of Building Information Modelling (BIM) and heritage recording have been presented as Heritage BIM 'HBIM', which is now a technique used to deal more efficiently with the tasks of management and documentation of these historic buildings. The most important issues that can affect this method are the modelling methods and determining the level of development (LoD), which can cause delays in project delivery times. This paper examines Heritage BIM for heritage buildings in Jeddah, Saudi Arabia. Both the manual and semi-automatic modelling methods are considered in this study, in addition to employing Hijazi Architectural Object Library (HAOL), focussing upon two main factors: the 'As-built' level of development (LoD) and project delivery time (PDT) from the architecture engineering perspective.

1. Introduction

1.1. Toward Heritage BIM

In the last twenty years, in order to make inventories and measurements of heritage buildings, a surveyor and equipment deploying traditional surveying techniques are selected to accomplish the task. The surveyor usually starts with the total situation to capture the key points on the site and the façade of the building. Afterwards, the surveyor refers to this key data using CAD software when returning to the office. The next stage is for the surveyor to draw up plans and elevations of the site or the building in 2-D. The generated data through this method is often inaccurate, time consuming and contains many errors, together with a lack of detail. It is also difficult to visualise 2-D plans in 3-D (eBIM, 2015). Even though these traditional surveying techniques do not result in an ideal outcome, it is ideal for the purpose of the BIM process, because of the heritage use of non-parametric CAD programs in order to generate plans for survey purposes (Thomson and Boehm, 2015).

Using BIM in the historical field has been introduced as a new method during the past few years, and is considered to be the fundamental stage towards the BIM workflow for retrofit and reconstruction tasks (eBIM, 2015). This method has been used in a number of research projects (Barazzetti, 2016; Chien et al., 2016; Dirix, 2015; Fai et al., 2011; Khodeir et al., 2016; Megahed, 2015; Murphy, 2012; Nieto et al., 2016; Oreni, 2013; Penttilä et al., 2007; Saygi and Remondino, 2013). The main theme of these research projects was to provide intelligent data (Fai et al., 2011), and an 'as-built' digital 3-D model (Backes et al., 2014), as well as for documentation, conservation and management purposes. Most of the research projects deployed terrestrial laser scanning (TLS) and photogrammetry techniques, described as 'Scan to BIM/HBIM', a term given to describe the survey procedure of capture into the 3-D model.

Murphy (2012) applied BIM for the purposes of recording and documenting classical architecture of the heritage buildings in Dublin during the period of 1700–1830 by using historic architectural data, as well as a mapping system for creating the library objects onto laser scan survey data. This method started with a remote collection by using the terrestrial laser scanner survey data, followed by point cloud processing and generating an ortho-image model. The next step of Murphy's method was to create a parametric library based on the laser scanning survey data using the architectural shape rules from the 18th century architectural pattern books. Murphy's library was created by employing the Geometric Descriptive Language (GDL) in the ArchiCAD program. Murphy claimed that the final HBIM outcome was a product consisting of 3-D models of the building including the detail behind the object's surface, relating to its methods of construction and material makeup, and HBIM can also automatically generate conservation documentation in the form of survey data, orthographic drawings, schedules and 3-D CAD models for both the analysis and conservation of historic objects, structures and environments. In relation to the Venice Charter in 1964, it is common in the conservation field to use the heritage

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Fig. 1. Nasif Historical House.

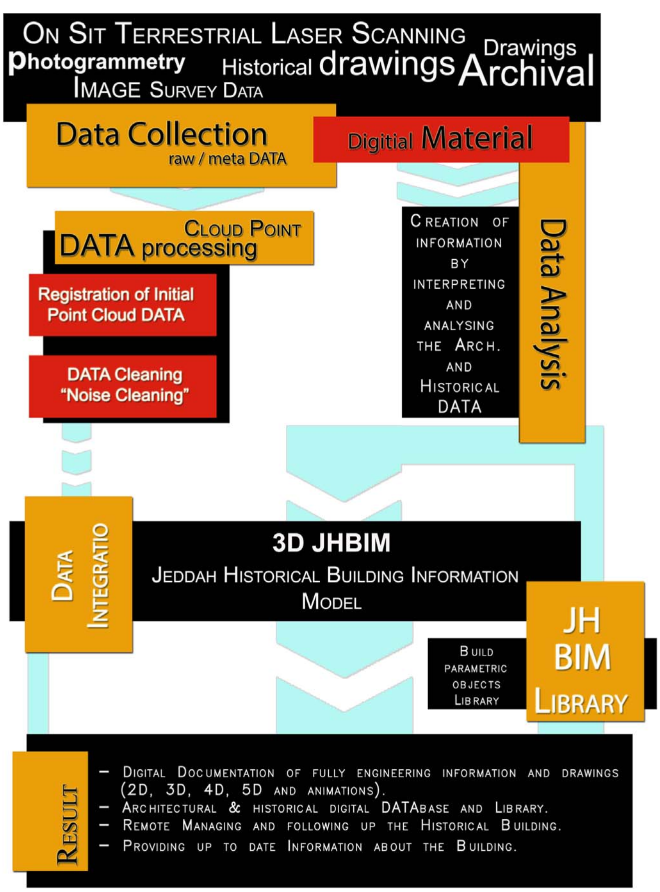

Fig. 2. JHBIM Method and workflow.

information to re-build the past of such historical monuments or to conserve them (Charter, 1964).

BIM can provide a number of benefits to the heritage field; for example, by providing a digital information model about heritage buildings (eBIM, 2015), providing a complete analysis of the suggested restorations and changes before final decisions can be completed. This process has the capacity to support the maintenance of buildings, assisting in budgeting for preservation and conservation, and providing community knowledge as models allow for review through open source viewer applications from remote places (Logothetis et al., 2015). According to Fai et al. (2011), “HBIM can provide automated conservation documentation and differs from the sophisticated 3-D models produced from procedural and other parametric modelling approaches, whereby the main product is a visualisation tool”.

1.2. Modelling in HBIM

The most important part of HBIM is transferring the information that is based on the rich data survey into 3-D parametric modelling. Since the BIM has been employed into the heritage field, almost all research projects use the manual methods of 3-D modelling and some are more likely to use the semi-automatic methods spatially to model the MEP (Mechanical, electrical, and plumbing) parts.

Since the last decade, the requirements of more advanced 3-D models for the purposes of documenting the built environment have appeared paramount, driving through the huge city scale modelling besides BIM within a smaller scale. The automation in modelling is becoming popular, since it avoids time-consuming, as well as costly manpower used in model creation. Currently, traditional surveying does not produce an outcome that is ideal for the BIM procedure, because of the historical use of non-parametric CAD programs in order to generate 2-D drawings. Consequently, a change in work procedure is required in both processes and display techniques for those who rely

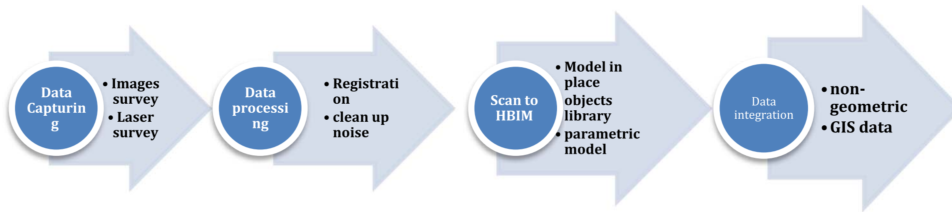

Fig. 3. Stages of JHBIM generation.

Fig. 4. Leica C10.

upon the development of this work (Thomson and Boehm, 2015).

In the case of the HBIM modelling process, the modelling represents the HBIM's objects construction that represent the heritage building components and parts, which contain both non-geometric and geometric features and relationships. According to Volk et al. (2014), if HBIM "is modelled on the basis of previously captured building information, the preceding data capture, processing and recognition methods influences data quality through the deployed technique and the provided LoD".

The key comparison between the modelling method is relating to modelling accuracy, or in the HBIM case known as LoD 'level of details/development' (Tang et al., 2010; Volk et al., 2014). Conversely, the standard for HBIM in the case of the LoD is not currently available. Some researchers have tried to establish their own standards as 'as-built' BIM modelling; the main problem with the 'as-built' BIM is the level of detail required that is captured through advanced technologies, such as laser scanning, which can be time consuming and is more expensive. In this case, it is very important to develop automated or even semi- automated modelling methods to resolve these issues.

By focusing on a number of research projects, it is widely agreed that automated BIM/HBIM modelling or changes of the models' surface toward volumetric model, and semantically opulent substances are in early stages of development (Arayici, 2008; Xiong et al., 2013). Several research projects have dealt with semi- automated modelling to build the surfaces or components for geometrical representations. On the other hand, such research failed to give sufficient attention to the component properties or semantic information (Arayici, 2008; Dai et al., 2010; Frahm et al., 2010; Klein et al., 2012; Xiong et al., 2013). In addition, the integration of non-geometric features, such as relational, economical, functional as well as semantic information of the heritage building, are always done through interactively or semi-automated methods (Donath et al., 2010; Hajian and Becerik-Gerber, 2010; Xiong et al., 2013).

2. Towards Jeddah heritage BIM

Similar to many historical buildings in Europe and around the world, building facades are of special interest in Historic Jeddah, such as the details of windows, balconies, stonework and ornaments that give each historic building its individual character (Böhm et al., 2007). Indeed, the historic district of Jeddah has a long history that goes back 3000 years (Telmesani et al., 2009). The Nasif Historical House is one of the most important buildings in the historic district that has been selected as the case study for this project (Fig. 1). The construction work of the Nasif Historical House began in 1872; in 1881 the building of the house was completed. The house is located in the centre of the historic district with the main reason for the building's position linked to the arrival of Sultan Abdul Aziz Al-Saud in the city in 1925. The Sultan lived in the house, where his Majesty joined with the most notable citizens of the city in a house that should be the most recognised and fitting habitation for the King. It can be noticed that the architectural characteristics of the house are comparable to other heritage building in historic Jeddah with Mashrabiyahs and Rowshans (SCTA, 2013). Recently, according to Nawwar (2013), the director of Historic Jeddah Preservation Department; the Jeddah Municipality is planning to reconstruct the building to be used as a museum and cultural centre of Jeddah. However, many of the historic houses in Jeddah, including the Nasif House, have no engineering data, which causes serious problems should they need to be repaired or rebuilt in the case of potential collapse or erosion due to human and environmental reasons, as well as other disasters, such as fire. (Figs. 2 and 3).

The deployment of Jeddah Historic BIM (JHBIM) is designed to compensate for this lack of knowledge and to generate full engineering information in the case of reconstruction and refurbishment requirements. JHBIM is an interactive solution that represents architectural periods based on Terrestrial Laser Scanning (TLS), Architectural Photogrammetry and historical data. The creation of these details for the Architectural Heritage Object Library is very important, because to build these unique heritage buildings in a 3-D HBIM model would be time-consuming to deliver in a complete form or 'as-built' level of detail (up to +/− 10 mm), and would affect the delivery time of the project (PDT). Each object of these historical buildings needs to be classified in an Architectural Object Library.

In the case of Historic Jeddah, Hijazi Architectural Objects Library (HAOL) is used. The Islamic Hijazi architecture is introduced and advanced scientific rules are documented for the production of architectural features, which support the design of parametric models. Additionally, introducing the historic data of Jeddah and Hijazi region, should provide the chance to improve details behind the object's surface concerning its techniques of structure as well as the material makeup. During the process towards JHBIM, the prototypes of the parametric objects libraries are modelled based on the photogramme-

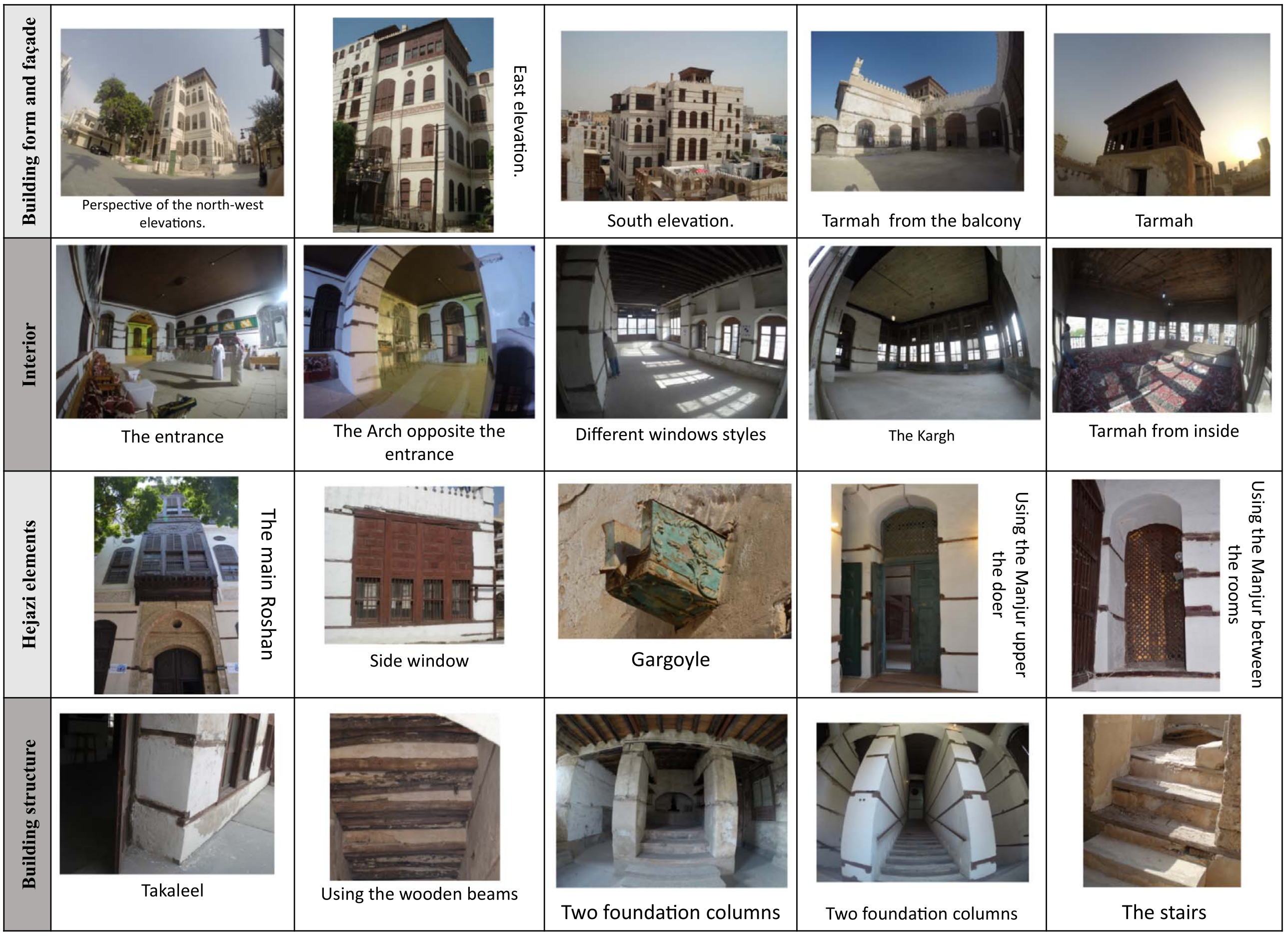

Fig. 5. The image Survey "Freestyle" Method.

try survey, and the point cloud data by operating method of different program platform management. Then JHBIM automatically delivers complete architectural engineering information, sectional, plans, working drawings, as well as three-dimensional data-rich models.

3. Scan to JHBIM

3.1. Technology, programs and equipment used

Leica scan-station C10 was employed to scan the house (Fig. 4). This laser scanning has many features, such as a range of view of 270° in the vertical direction and 360° in the horizontal direction, and this feature allows for capturing full panoramic views (Leica Geosystems, 2013). Another feature regarding the scan method is described as 'time of flight dimension principle', and the Leica C10 can scan between 2 and up to 300 m. To deal with the laser scanning point cloud, both Leica Cyclone® version 8.1.1, and Autodesk Recap software were used for the registration process and removing noise from the laser scanning data. In addition, for the image survey step, a professional Nikon D5100, 18-mega pixel camera was used, and the 3-D JHBIM model was built by using Autodesk Revit 2015.

3.2. Image survey

To complete the JHBIM project, the on-site work began with the image survey step, which was intended to highlight and document the Hijazi architectural features for the House.

The image survey of the house involved ten working days (from the 12th to the 25th of August 2014), and highlighted that the house has very unique architectural features related to different Islamic cultures and ages, such as the Roshans and Mashrabiyahs, which were borrowed from the Ottoman culture (Fig. 5 shows some of the house's architectural features).

3.3. Terrestrial Laser Scanning Survey

The scan of the house involved initial preparation of the location to indicate the scan-station points to obtain a good overlap between these scan-stations, and to achieve high-quality scanning, the HDS W/B 'White and Black' six inch circular targets technique was employed (Fig. 6) and shows the site preparation step and about 400 'W/B′ targets were used. The preparation of the location lasted for more than five working days. To obtain a successful laser scanning survey, especially in the case of historical sites, it is extremely important to define the best suitable viewpoint locations, because the amount of achievable scan-stations is normally limited through the complexity of the structure and site. After preparing the location, the next step involved the laser scanning survey, and to obtain high accuracy in the laser survey, at least three (W/H) targets needed to be in common with each of the overlapping scan-stations (Fig. 6). The scan-stations involved about 150 scans (about 112 h overall), which produced more than 70 GB of the LIDAR data with a resolution of 50 mm and 10 m distance inside of the house, and up to 70 m outdoors. The laser-scanning step took over ten working days to be completed. (Figs. 7 and 8).

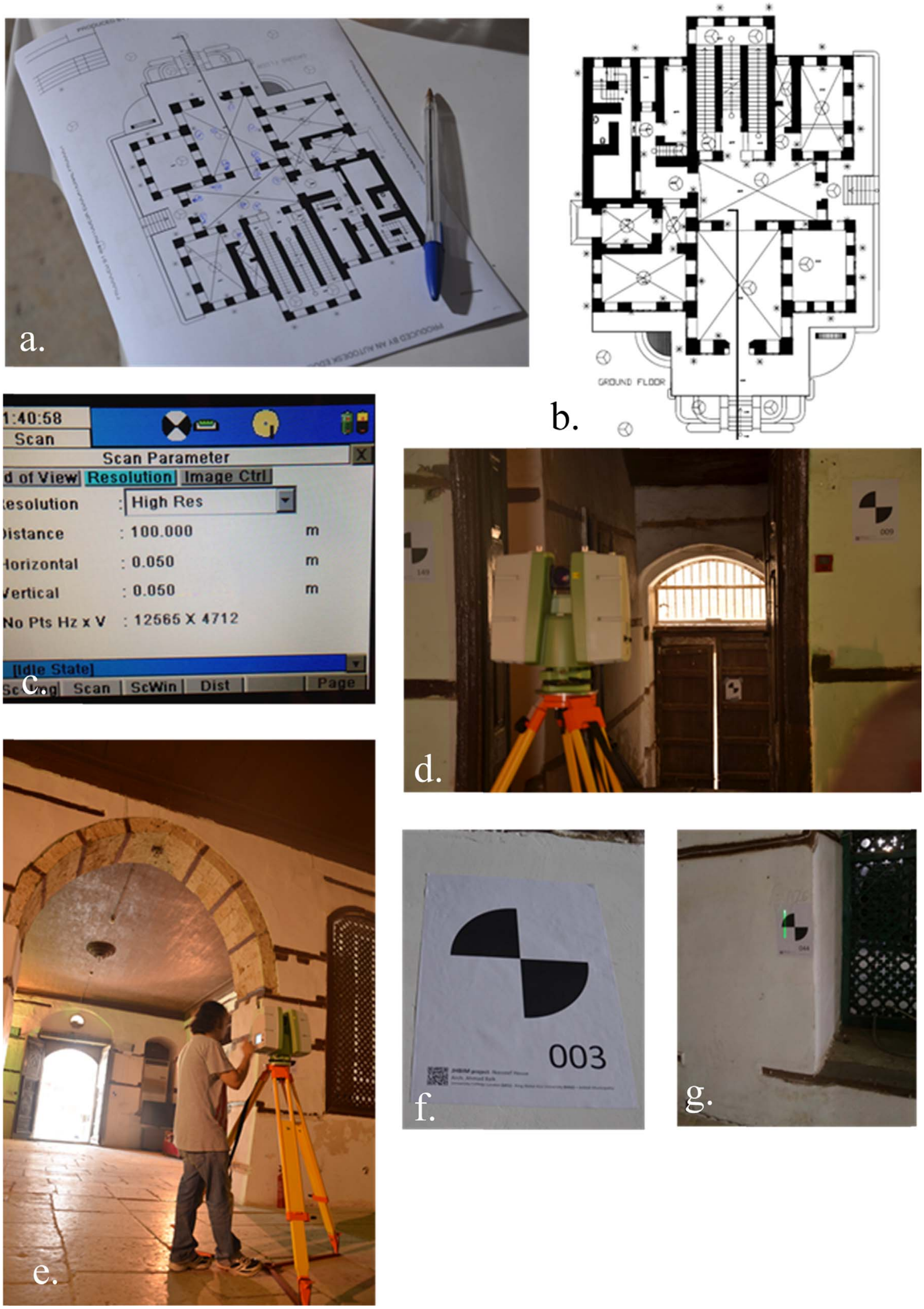

Fig. 6. Terrestrial Laser Scanning Survey process. (a.) Planning the scans locations. (b.) Planning the targets and scans locations. (c.) The scan resolution. (d.) Starting the laser scanning. (e.) Picking the targets. (f.) and (g.) Scanning the targets.

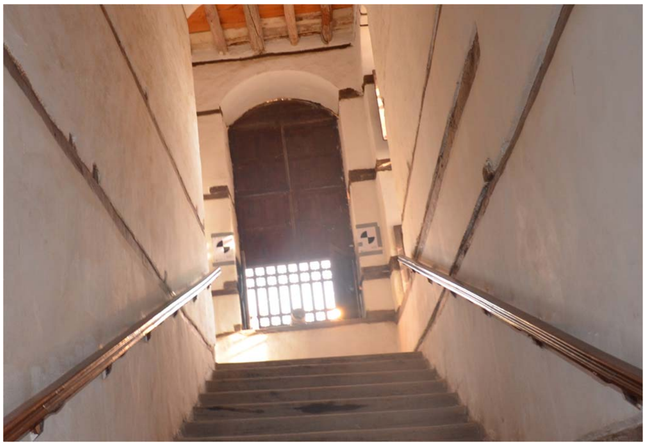

Fig. 7. Locating the W/B targets on the wall of the staircase (Author: A.Baik).

3.4. Point cloud data processing

A wide range of data is collected by laser scanning represented in 3-D coordinates, and defined as 'point cloud data'. Advanced software is required in order to cooperate with the massive amount of 3-D LIDAR data. Whilst laser scanners could take a few minutes to scan millions of accurate 3-D points, there is considerable work involved in converting this data into a 3-D model containing useable information. After exporting the laser scanner's data outside of the scan, there are numbers of convenient applications that can be employed to prepare and to remove the noise from the LIDAR data. In this project, Leica Cyclone® was used to remove noise (Fig. 10) and completion of data processing required ten working days. Several Scan-Worlds were then linked for the registration step via corresponding points in overlapping sections, (Fig. 9) illustrates the registrations step for more than two Scan-Worlds that were scanned for the Nasif Historical House. Fig. 11 shows the developing combinations of laser scans for a 3-D point cloud model. Furthermore, the standard point cloud model resolution for the case study surfaces was 70 mm. (Fig. 12).

4. JHBIM modelling

The purpose of employing HBIM for historical Jeddah buildings was to develop more advanced modelling in order to move outside of the basic level of BIM 2-D drawings towards further advance of BIM levels level two and level three (Baik et al., 2014) to support the preservation and share data of these heritage sites with professionals, experts and others participating in decision making processes (Eastman et al., 2011; Fussel et al., 2009). Saygi et al. (2013) states that "BIM will provide the possibility to represent all views (3D model, plans, sections, elevations, and details) automatically. These findings are supported by Murphy et al. (2009) who suggest that the concept of employing BIM in the historic field of research is to provide interactive parametric objects that represent architectural elements to model historical monuments from TLS data.

The modelling step of the JHBIM model of the Nasif Historic house started once the 3-D point cloud had been received. Some parts of this 3-D point cloud are selected to be modelled separately for the HOAL library, such as the Rowshan and the Mashrabiyah, and to be inserted to the model later. This step aims to reduce the complexity of the historical building and complete the project. Through simplifying the heritage building and separating the architectural objects out from the building structure, the building's main body is modelled based on the 3-D point cloud. In the case of the Nasif Historical House, Autodesk Revit 2015 is used as it provides quick modelling and allows changes to the 3-D model, as well as a high standard of structure documents, and provides a high standard of flexibility.

The modelling steps began with building the house's external and internal walls of the lower floors and then the upper floors (Fig. 13). Next, starting to simplify the façades as simply as possible (Fig. 14). In this step, it was very important to build the house by using traditional methods of construction, which had been used to construct the house, to enable the calculation of loads on the walls and the floors for any future use. (Fig. 15).

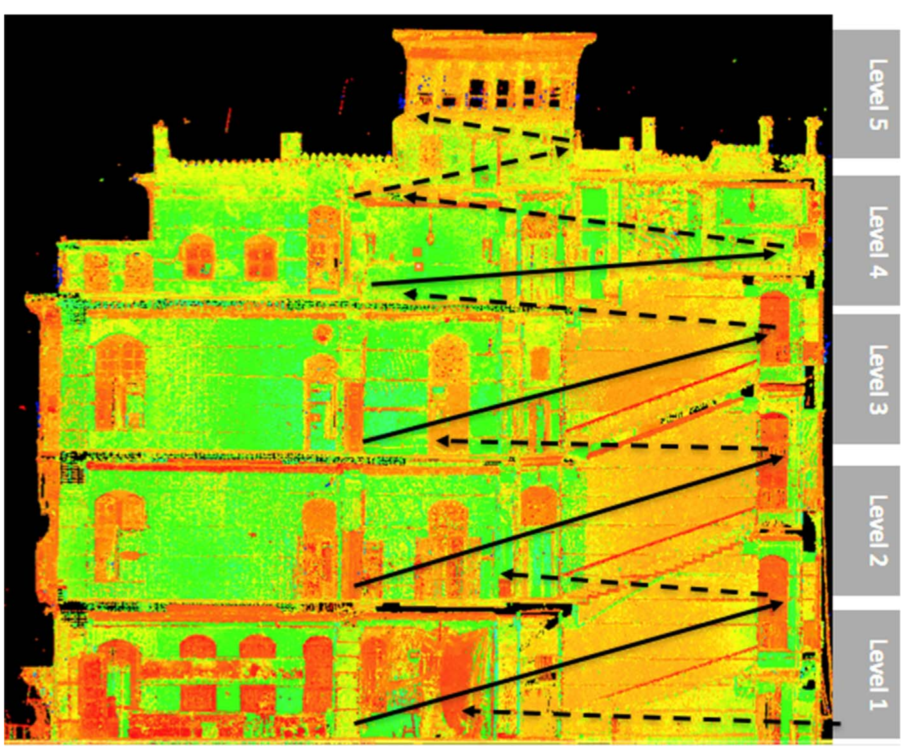

Fig. 8. Section on the 3-D point cloud after using the staircase to link the floors' scans and to register the scans.

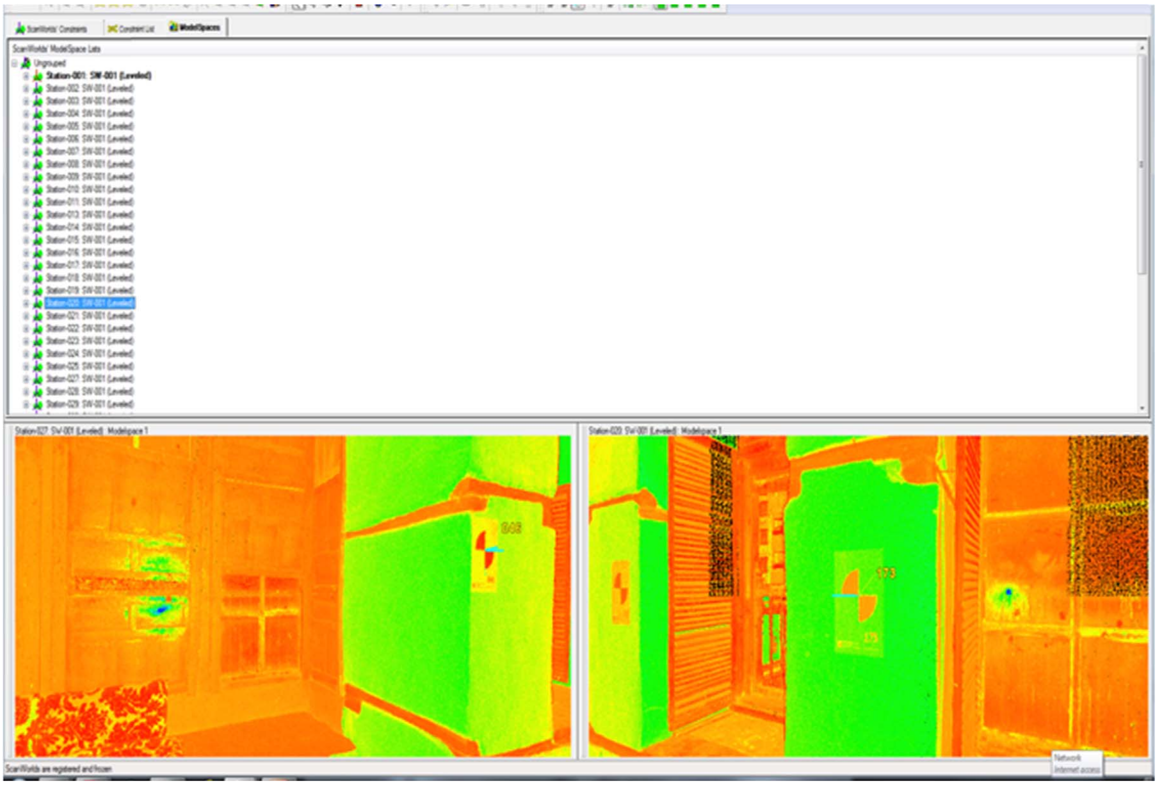

Fig. 9. ScanWorlds registration.

The second step, which involved using the HAOL as a plug-in for the model, saved considerable time and work. However, some objects of the HAOL, such as the windows, Rowshan and doors, were modified to fit exactly on the model. This is because most of these architectural components had been thoroughly considered and designed on-site to be built into particular areas within the historical house (see part 4.1).

The third step was to add any available BIM layers, such as structures, ventilation, electricity, water, sewerage, and air conditioning. Some of this information is sourced from the previous engineering works and reports that have been completed over several years.

The fourth step is described as the "make-up" step for the JHBIM model, which requires adding the details, which can provide a realistic sense for the model.

4.1. Modelling of the Hijazi architectural object library

As with many historical buildings in Europe and around the world, buildings facades are of special interest. In Jeddah, the details of windows, balconies, stonework and ornaments give each historic building its own individual character (Böhm et al., 2007). Each object of these historical buildings must be classified in an architectural object library. The HAOL is designed to reproduce Hijazi elements as 3-D computer models, which are modelled using a Revit Family (RFA). The HAOL is based on close-range image survey data, the LIDAR survey data, and Hijazi Architectural pattern books, such as 'The Coral Buildings of Suakin, Islamic Architecture, Planning, Design and Domestic arrangements in a Red Sea port' written by Greenlaw (1995), to reduce the modelling time or project delivery time (PDT) and provide a high LoD. Through employing HAOL, it is possible to re-establish elements of the past in order to preserve or to rebuild these unique elements of Hijazi heritage buildings. The objects of Hijazi buildings, such as Mashrabiyah and Roshan, turn into a vocabulary of the heritage building in Jeddah, and these unique architectural vocabularies are the key purpose of the beauty of these houses. However, there is a considerable lack of knowledge regarding the HAOL to represent these unique objects, and because of these concerns that HAOL has been introduced. Taking into account the level of detail is extremely important, as well as determining how can these object models can be simplified to best suit the conservation project. It provides a real opportunity to change the parameters of architectural understanding, and especially for objects that are unrivalled and irregular, such as in some of Jeddah's historical buildings. A positive outcome allows opportunities to match the objects' real dimensions with resulting data adding to existing engineering blueprints, which provides the real conditions for models. The concept of an object library is to insert these objects as plug-ins into existing BIM programs. In addition, the HAOL is presented and available for any future projects in the historic district.

The principle behind the JHBIM objects library commenced with understanding the purposes and the requirements of the LoD project. This step is significant, since it is necessary to define the appropriate quality standard of the model required. Practically, there is no official standard for the level of detail in the case of 3-D heritage building modelling, and much depends on the purpose of the HBIM model. For the JHBIM model, the level of detail will be high (+/− 10 mm). This is required for any reconstruction work for both the building's woodwork and the structure of the building in order to meet the world heritage standard.

The second step is classifying the objects based upon a number of aspects; for example, the form, the style and the amount of detail required for these objects. The objects in the library were initially divided into five main sections i.e. 'Roshan, Gate, plaster, penthouse and Manjur pattern' (Fig. 16).

The third step is simulating these parts in 3-D BIM environment software; for example, Autodesk Revit platform. The outline of generating the HAOL began with studying well-known architectural rules of the Hijazi elements through understanding and simplifying these objects and dividing them into main parts and sub-parts. This

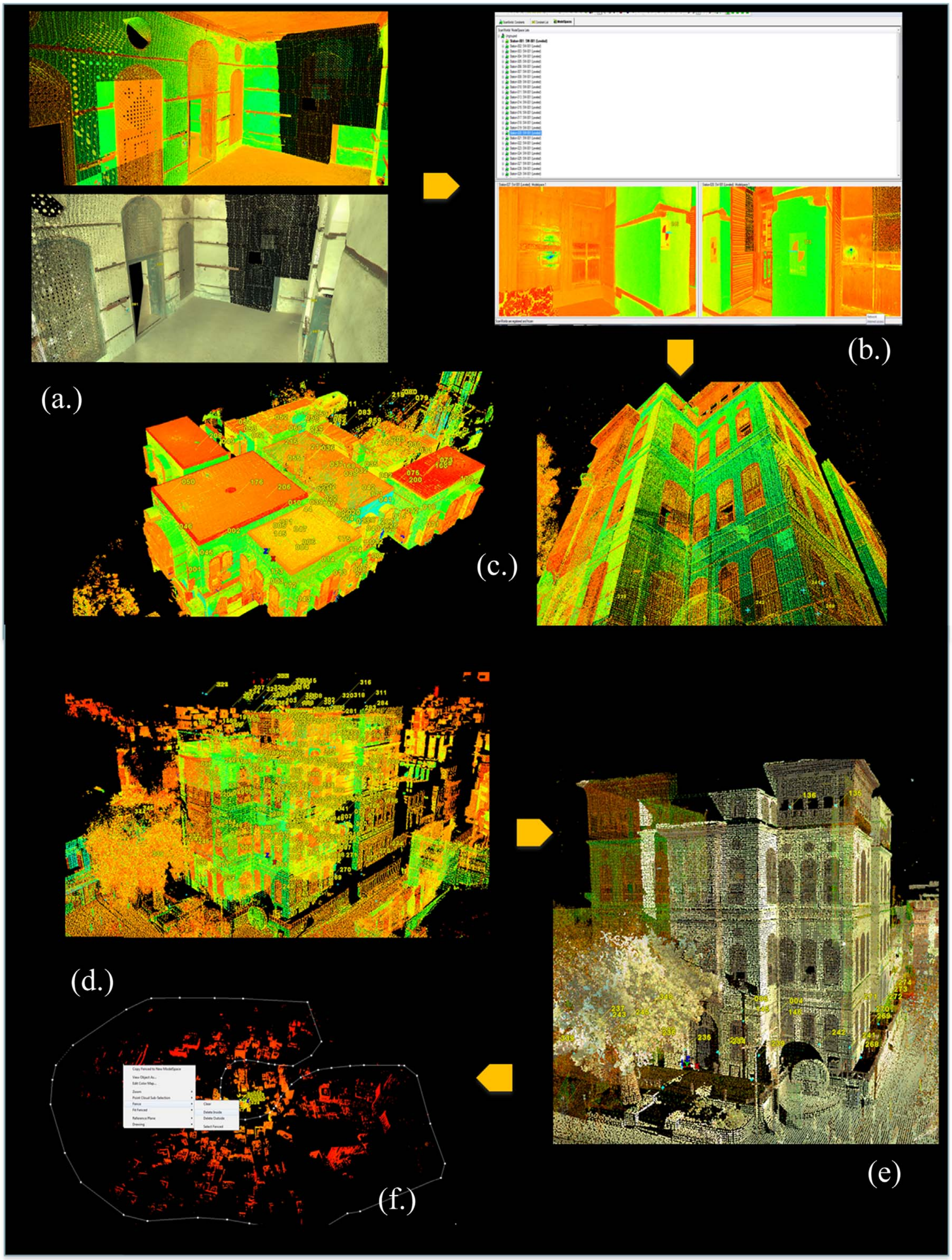

Fig. 10. Point Cloud Data Processing for Nasif House. (a.) Point cloud with/without image texture map. (b.) Registration of the scans' point cloud. (c.) The results of the registration. (d.) The results of registration for all the scans. (e.) Applying the image texture map. (f.) Cleaning the noise.

step allows for decreasing the complexity, and making recognition easier. The next step is creating a frame for the objects structures, and then modelling each part closely to the real form in 'as-built' level of detail'. Finally, this multiple information is incorporated to provide the complete 3-D model of the Hijazi objects, which is suitable for inclusion in the Heritage. (Fig. 17).

4.1.1. *Modelling the Roshan "example"*

The Roshan can be described as a large projecting wooden structure on the Hijazi houses facades, with a recognisable latticed component. It is necessary to give more attention to Roshans, since they are characteristic symbols of the architectural heritage of Jeddah city, and they are located in most of the historic district buildings. The

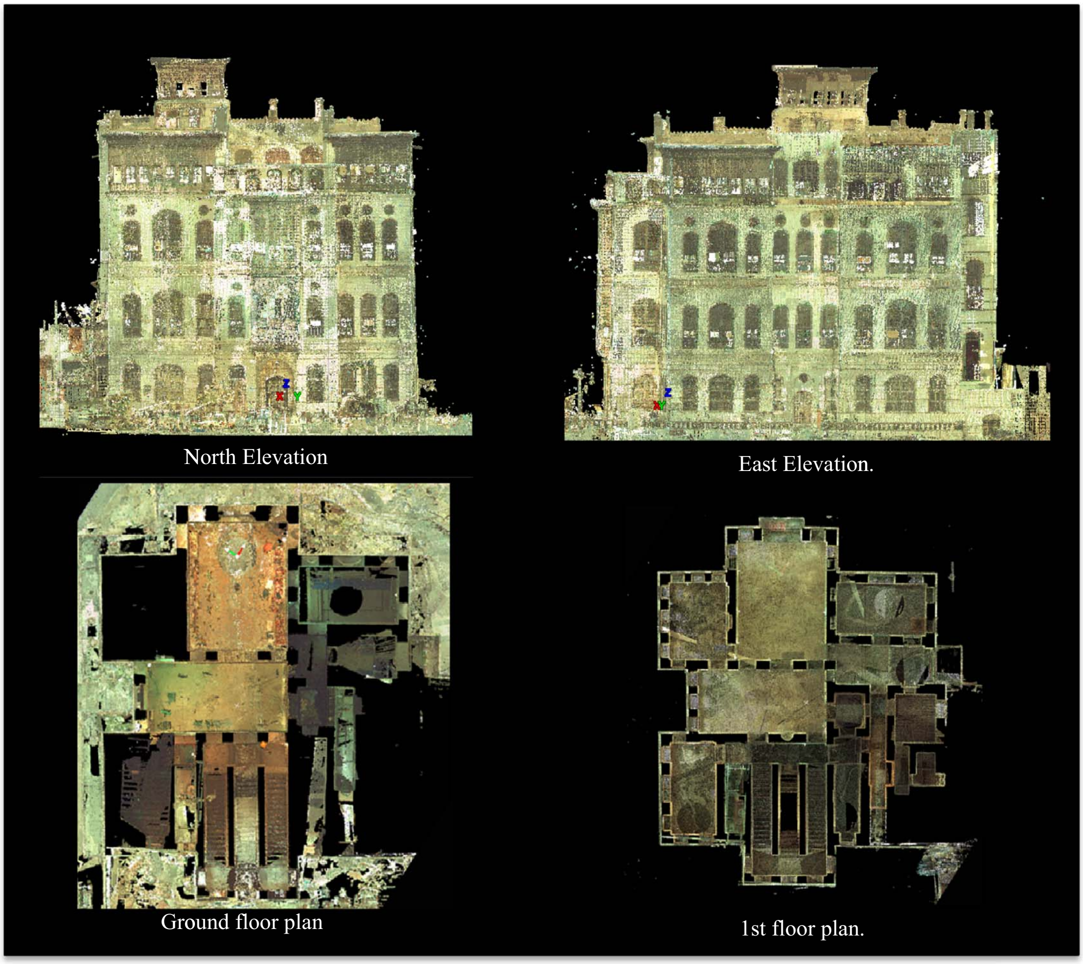

Fig. 11. The resulting combinations of scans for 3D point cloud model.

Fig. 12. 3D Point cloud of Nasif Historical House and the main Roshan.

Fig. 13. modelling the first floor walls.

Fig. 14. Modelling the main façade of Nasif house.

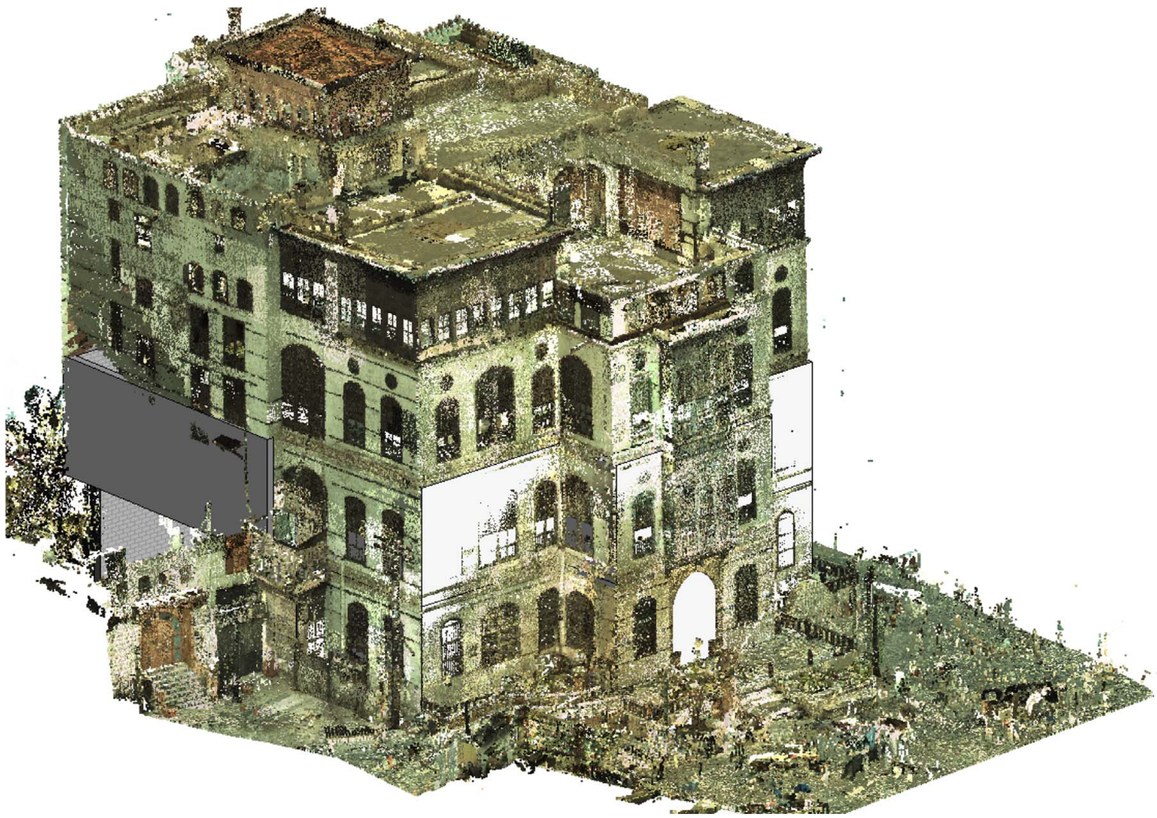

Fig. 15. Preparing the 3d model For insarting the HAOL.

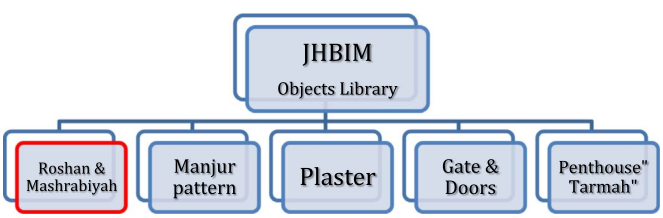

Fig. 16. JHBIM objects library layout.

Roshan unit is created by a front and two sides boards, and by a ceiling and a floor. The whole Roshan's structure is firmly tied to the brick through a series of wall brackets or consoles. These consoles incorporate elaborate, and in some cases, polychrome ornamentation. The under-face is partly made up of small wooden surfaces and designs in 'steps'. These wooden surfaces are carved and decorated, and lay on console underpins inside the brick. The side boards are stapled over the opening, utilising metal spikes tied into the width of the wall.

By providing this level of detail for the Roshan, it is possible to protect these from any further deterioration. In addition, documenting these Roshans and their components by using the most recent digital approaches, together with the application of the most suitable repair methods ensures longevity of preservation, conservation of value and authenticity (Adas, 2013).

Modelling the Roshan at this 'as-built' level of detail (LoD) takes about seven working days, Fig. 18 shows the steps for modelling the main Roshan in the Nasif Historical House; these objects are used as plug-in extensions for the Jeddah Heritage BIM process. (Fig. 19).

5. Discussion

As a result of the complexity of reverse engineering the existing structure, the creation of the JHBIM model of the Nasif Historical House is treated as an iterative modelling program. This project faced a number of challenges; for example, the huge amount of data, which was generated via TLS, image survey, and the on-site inspections, as well as a large amount of Roshan details, all of which needed to be modelled. The first version of JHBIM model delivered a useful environment to compare and resolve the complexities of several existing data sets. It was also found that JHBIM approach for the complex task of modelling a historical building requires to be reviewed spatially, in terms of the level of detail, as well as the structure of these buildings. Despite this, JHBIM provides a strong basis for the assembly of components that can be repeated in many sites. Using, HAOL into JHBIM model was effective in different ways. By reducing the time required for building modelling, providing an architectural objects library for Hijazi objects was highly detailed. These objects can then be used for new heritage projects in the future. In case of heritage projects, some of these objects need to be modified significantly to be suitable for the location.

The heritage conservation of Jeddah historical city gains advantages in addition to the development of JHBIM, which supports the documentation, context, information about the materials, structural techniques as well as the building pathologies. JHBIM provides a range of wide-ranging of materials that are not presented outside of the standard libraries for the three-dimensional model parts. JHBIM is able to provide benefits for the cultural heritage conservation of Historic Jeddah; for example, by "offering a full study of proposed renovations and changes before final decisions are made, assisting in maintenance efforts, damage detection on building's surfaces, planning for maintenance and repairs, and allowing wider public building experience as models can be viewed with free viewer software from remote locations" (Baik et al., 2013). Therefore, virtual exteriors and interiors visits of heritage buildings, as well as improvements to the performance of heritage building management, and enhances understanding to inform decision-making procedures for conservation, can

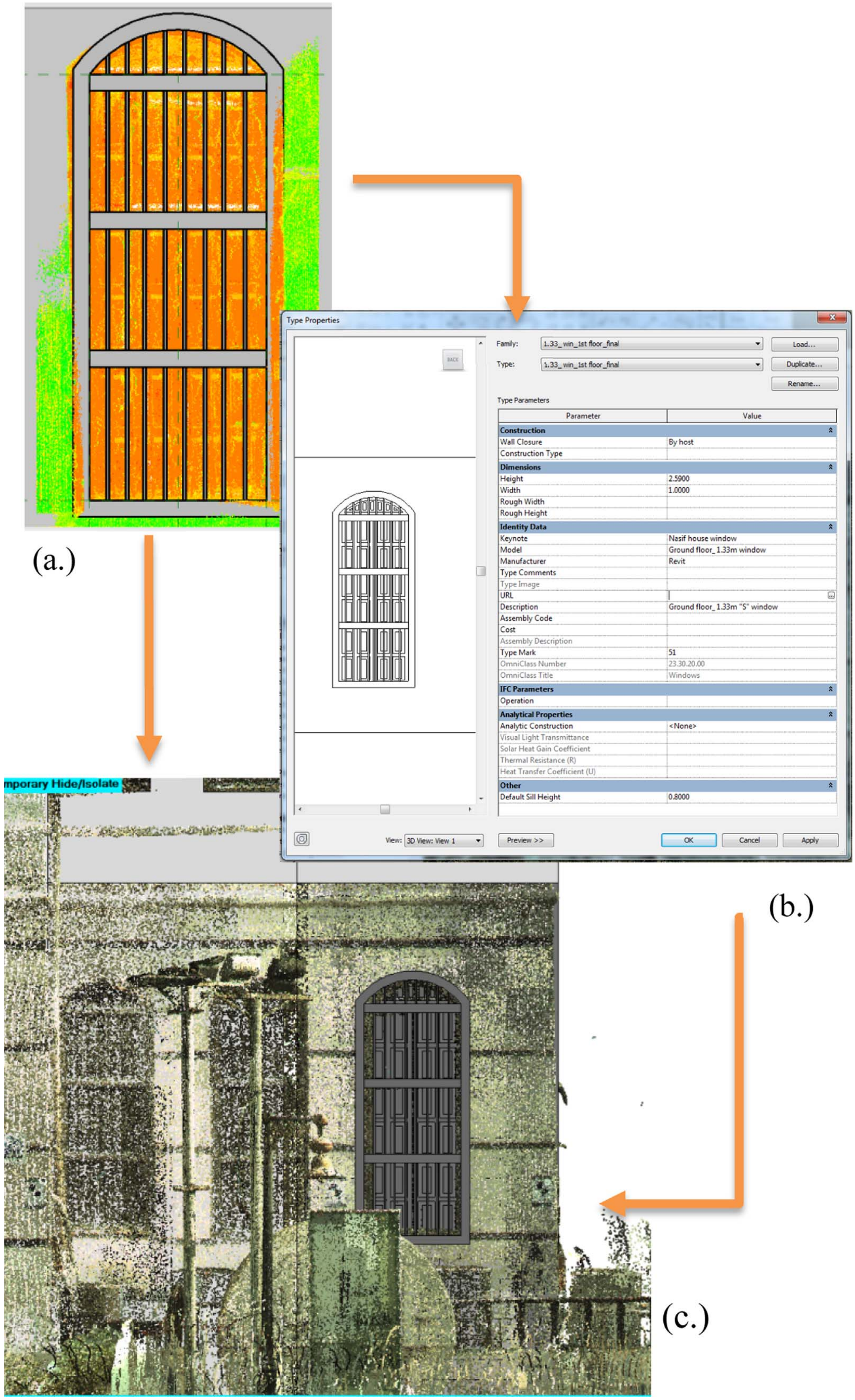

Fig. 17. Modelling the window as a Revit family block to be inserted into the Nasif house project. (a.) Modelling the object based on point cloud. (b.) The properties of the object. (c.) Placing the object into the building.

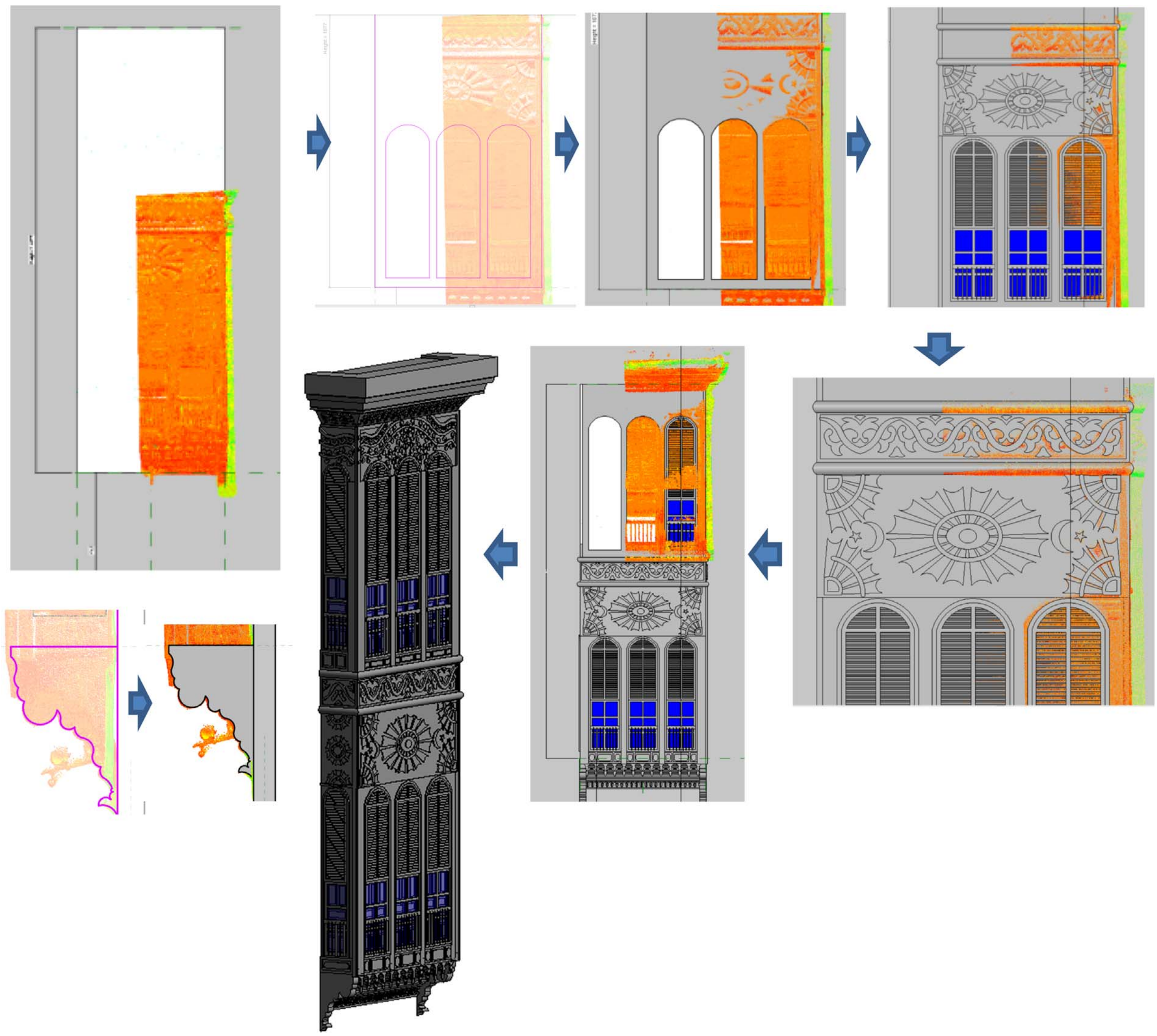

Fig. 18. Steps of modelling the main Roshan of Nasif Historical House.

be achieved through the use of JHBIM, Fig. 20 and shows the 3-D JHBIM model of the case study “Nasif Historical House”.

Fig. 21 shows a 3-D section about the JHBIM model and the 3-D point cloud. The development of the 3-D JHBIM model is employed for reconstructing some of the parts, and to preserve and to restore the unique elements of heritage monuments. (Fig. 22).

6. Future work and conclusion

Future studies could integrate JHBIM model and GIS data of Historic Jeddah and the Nasif Historical House to provide semantically rich models. Recent studies show the significance of employing 3-D GIS and BIM in the case of cultural heritage conservation (Dore and Murphy, 2012; Jayakody et al., 2013; Lorenzini, 2009; Saygi et al., 2013; Wua et al., 2013) Fig. 23 shows the 3-D JHBIM model after being exported in 3-D PDF format provides a rich interactive database of these projects. The development of these models is significant, as well as being suitable for the purpose of heritage documentation and conservation of more than 1442 buildings in Historic Jeddah. Such integration should enable advantages beyond BIM and 3-D GIS procedures to further support the purposes of documenting and analysing the cultural heritage buildings in the district.

To summarise, the methodology of JHBIM and HAOL is separated into three steps; firstly, on-site data capture employing range/image-based methods; secondly, LIDAR data processing; and lastly, describing and modelling the historic house by applying the objects library in the BIM environment. In addition, this approach is evaluated, indicating the possibility of BIM method to be employed for documentation of the Hijazi Historical House and its elements. The aim of this study is to create architectural object libraries based on the surveys. The achieved outcomes of the 3-D architectural information have been surveyed and created depended on TLS and Photogrammetry survey technologies.

The building of the JHBIM model lasted for more than six months, but by inserting HAOL into the JHBIM model the timescale was reduced with the resulting the project delivery time of around twenty working days. Employing these advanced technologies has assisted and speeded up the procedure of creating architectural drawings for the wooden parts and ornamental details of the heritage building elevations. These significant developments are based upon the amount of detail and the accuracy of parametric objects since JHBIM can automatically create complete engineering drawings, 2-D orthographic sections, plans, 3-D models, schedules and sheets. All of the resulting information is available for several purposes, such as planning, restoration, documentation, education, GIS and sharing the information about the heritage monuments with professional consumers and experts involved in the decision-making process.

Fig. 19. 3D LiDAR point cloud of Nasif Historical House.

Fig. 20. 3D model of Nasif Historical House based on JHBIM.

Fig. 21. 3D section on the JHBIM model and the point cloud.

Fig. 22. Nasif Historical House JHBIM model after the rendering in Autodesk Revit.

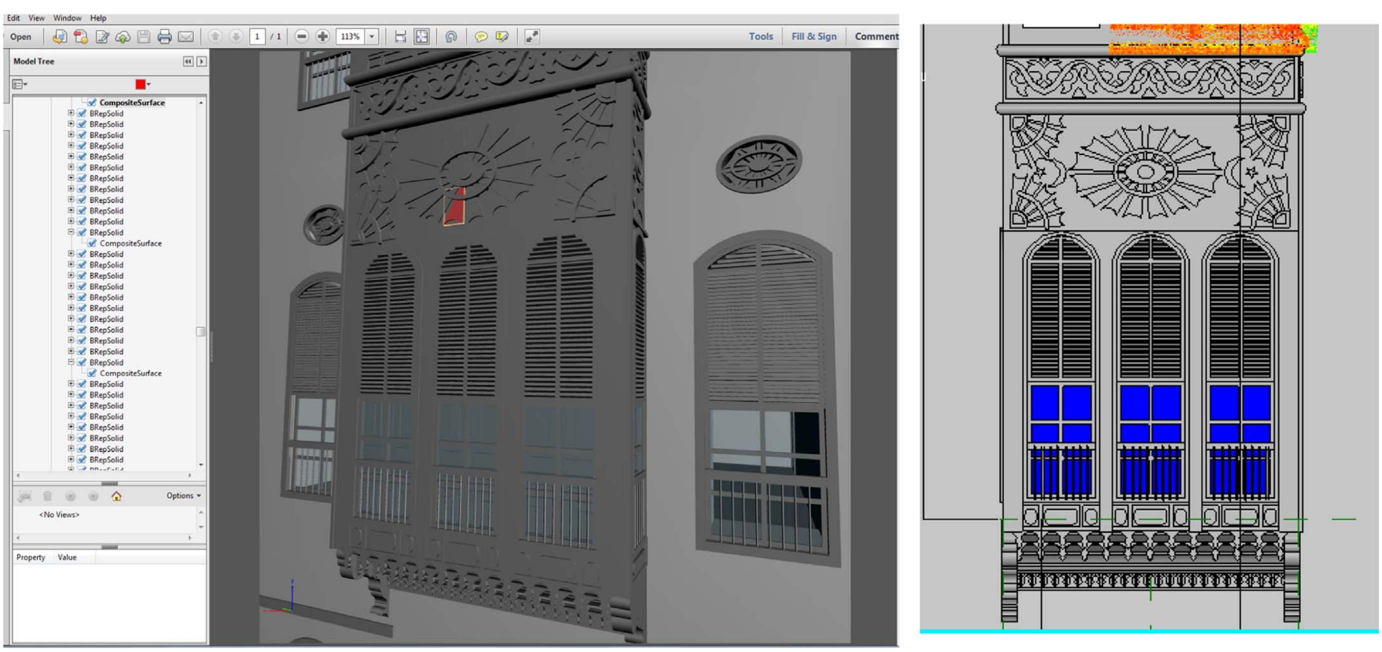

Fig. 23. Lift Side the JHBIM model after exported in 3D PDF. In the right side the JHBIM model in the Autodesk Revit.

Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.daach.2017.02.001.

Video 1. The 3D JHBIM model of Nasif Historical House, Jeddah, Saudi Arabia. A video clip is available online. Supplementary material related to this article can be found online at doi:10.1016/j.daach.2017.02.001.

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