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SCAN-TO-BIM APPROACH TOWARDS PRODUCING QUANTITY TAKE-OFF OF HERITAGE BUILDINGS IN MALAYSIA

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Abstract

Cost estimating of heritage building conservation is often tedious and challenging due to the lack of information, especially on the cost and as-built information. In addition, the conservation method is complex, and quantity surveyors often find it difficult to source the required materials that may not be available. In Malaysia, although heritage buildings conservation is progressing cost information and relevant documents required for conservation are still lacking. Hence, jeopardising the accuracy of cost estimation of heritage building conservation in Malaysia. Heritage Building Information Modelling (HBIM) technology has become a solution to the traditional approach of building conservation practice with its capability to integrate the 3D terrestrial laser scanners. Past studies on HBIM and the use of 3D laser scanners focused on the construction of the as-built Building Information Modelling (BIM) model. However, quantity surveyors' ability to perform their professional practices on the HBIM platform and the use of 3D laser scanners for heritage building conservation is less explored. Thus, this paper provides the basis for the research approach that will be used to achieve the study's goal; (1) 3D data collecting, (2) data processing, (3) as-built BIM production, and (4) quantity take-off are the four primary phases of the technique. This research is significant in removing all the time-consuming processes involved in manual design revisions and quantities measurement while improving the visualisation of construction operations.

Keywords: Cost estimation, HBIM, Heritage building information modelling, Heritage buildings, Quantity surveyors.

1. Introduction

Quantity Surveyors (QS) are one of the key players in the construction field in Malaysia. The quantity surveyor's role is to provide cost management and cost estimate service for a project. A QS's main responsibility is to provide financial monitoring, expense, and contract management of a project at all levels [1]. According to Lee and Lim [2], since Malacca and George Town were listed under UNESCO's World Heritage Sites on 7 July 2008 as historical cities, the demand for quantity surveyors in Malaysia has increased due to the awareness of the importance of conservation of heritage buildings. A country's historical past and culture are reflected in heritage buildings and combined to form a city's or country's architectural legacy.

Heritage buildings possess heritage values resulting from their significant architecture and their correlation with important heritage events such as religious, social, and political events. However, heritage buildings have deteriorated over time and face many challenges. According to Heritage Canada Foundation [3], about 20 per cent of heritage buildings before 1920 have been lost to demolition over the last 30 years. There are approximately 39,000 heritage buildings built between 1800 and 1948 and located respectively in 247 cities and towns in Malaysia. Hence heritage buildings represent a considerable portion of building stocks in Malaysia [4]. According to Mustapa et al. [5], the number of heritage buildings in Malaysia is limited, suggesting the importance of conserving heritage and traditions.

Concurrently, the trends of HBIM have become a widespread phenomenon in heritage conservation practice in recent years [6]. According to Murphy et al. [7] and Dore et al. [8], HBIM inherits all the characteristics of BIM, which pursues the modelling and documentation of architectural elements, according to artistic, historical, and constructive typologies. Such processes are structured and depend on centralised modelling. This study aims to explore the application and potential use of 3D laser scanning technology as an extension of Heritage Building Information Modelling (HBIM), to support the process cost estimation in conservation projects. As Malaysian heritage buildings have unique characteristics, a case study approach adopting the HBIM process was adapted to investigate the parameters of HBIM in developing accurate quantity take-off for cost estimation.

2. Research Problems

Lim and Ahmad [9] asserted that heritage building conservation practices depend highly on traditional approaches. The cost estimation of heritage building conservation works is complex as it is of a different approach from the preparation of cost estimation for new building works. In contrast to new building works, heritage building conservation might be impacted by insufficient as-built drawings and information. Occasionally, even if the as-built drawings and information are available, they might be outdated [9, 10]. Conservation of heritage buildings involves multidisciplinary participation; due to this nature, several issues lead to complexities. For example, due to fragmented practice in heritage building conservation projects, a lack of understanding and confusion about the level of conservation work required has resulted in frequent challenges in estimating works for heritage building conservation [6, 11].

Moreover, the scope and extent of conservation are not demarcated due to the dependency on the conventional approach. Thus, uncertainty, unreliability, and poor decision-making frequently occur in heritage building conservation projects. Similarly a renovation works, restoration typically takes place in scattered locations within an established restricted site [12].

Harun [13] explained that heritage building conservation works are activities conducted to enhance the life span of the building. It is different from constructing new buildings as it usually involves refurbishing existing buildings [14]. Typically, requiring a lesser workforce, but the operation is extremely intensive as the works are disseminated throughout the building. According to [9], in Malaysia, cost estimating for heritage building conservation works usually follows the traditional procured approach, using Bills of Quantities. The traditional procured approach is the most appropriate for selecting an expert contractor at a competitive price [15]. Furthermore, Lee and Lim [2] stated that the traditional remeasurement methods involved a detailed exploration of the building, using photographic shooting, on-site measurement, and observation.

However, such a process and the timescale to conduct manual measurement are often laborious, time-consuming, and tedious [16]. For instance, the accessibility to on-site measurement issues arises, particularly for unreachable and hazardous areas and elements of buildings [17]. QS must be cautious to ensure minimal contact and alteration to the building fabrics during on-site measurement. Furthermore, during the on-site manual measurements, personnel are exposed to hazardous materials such as asbestos and fungus, which are commonly encountered during the on-site measurements of heritage buildings [17].

Quantity surveyors are at risk of falling from high places or becoming trapped in enclosed spaces while on-site measuring since heritage buildings are designed with little regard for accessibility [18]. It also added that, even with an escape route available, it is still dangerous due to the ageing of the buildings. Currently, there is a shortage of trained personnel in preventive maintenance and technical preparation for new skills and knowledge within the traditional heritage-built sector [19], suggesting a low-level of experience in executing an HBIM-enabled heritage building conservation. As traditional buildings have unique characters and complexity, urgent measures are required to define the user's experience and the parameters needed to perform such a process.

Furthermore, there is a lack of workforce to facilitate proper practices of conserving such heritage buildings. Hence, to tackle the limitations and challenges, HBIM, using a 3D terrestrial laser scanner, has been adopted in building conservation to replace the traditional approach for a QS to conduct the cost estimation works. However, QS has little or limited involvement in performing HBIM practices using 3D terrestrial laser scanners for conservation projects [20]. Moreover, the current adoption of BIM in Malaysia alone is scarce and experienced low adoption and experience [19, 21]. Hence, an extended study of HBIM, with evident case studies, is needed to ensure growth for the Malaysian construction sector [22]. Thus, this study aimed to explore the potential of HBIM and identify how HBIM could influence the practice of quantity surveyors, particularly heritage building conservation projects using the Scan-to-BIM approach.

3. Literature Review

3.1. Definition of heritage-building information modelling (HBIM)

The widespread use of 3D laser scanning and photogrammetry technology has influenced an innovative practice of recording cultural heritage sites. This process has enabled HBIM to become a well-known tool that aids in discussing historic buildings [6]. HBIM is an emerging approach with a strong potential for incorporation into the life cycle of construction projects which would pave the way to become the industry norm for construction projects and become a key factor in the future procurement of projects [6]. HBIM's approach to building design, construction, and management involved using a centralised digital model to automate the entire project team. The project team members must be able to communicate to coordinate accurate building information on a digitised and shared common platform to maximise the process of heritage building conservation [1, 10, 23].

HBIM's most important process is to generate the necessary parametric model to convert the surface of the constructed facilities to the desired model. According to Guarnieri et al. [24], the process of HBIM involves a few steps, namely, Data Acquisition, Data Processing, and Data Fusion. However, such workflow is still needed to be defined to identify any issues; required data and processes are still a field that requires clarification. It is also worth noting that HBIM has been discussed in the Malaysian construction industry for a long time and has grown in popularity among all construction professionals in the Architecture, Engineering, Construction, and Facility Management communities, as such exploring HBIM parameters would certainly strengthen the image of the industry [25].

3.2. HBIM for quantities take-off

According to Cheng et al. [26], to obtain data, it is common and a trend to use 3D laser scanner technology, which offers an effective process of acquiring 3D data for HBIM. The 3D data acquisition process indicates the creation of HBIM objects that represent the information of the building, including its sections, details, orthographic projections, and schedules [27, 28]. Prior knowledge related to the potential of HBIM achieved by a 3D laser scanner has been considered for creating as-built BIM for heritage building conservation works. This knowledge is crucial for quantity surveyors to build an as-built 3D model of the heritage building and, subsequently, to prepare cost estimation of works required for the necessary conservation works. Furthermore, according to Sacks et al. [27], most BIM-based estimating systems can export quantities to a spreadsheet or other databases, allowing the quantity surveyor to begin estimating. Quantity surveyors usually feel that exporting amounts to Microsoft Excel format is sufficient for their BIM work.

According to Hardin and McCool [29], exporting quantities is inefficient unless the BIM model and the spreadsheet or database are linked, so the latter is automatically updated with changes to the former. Such output will still deliver the simplicity and control that certain workflow requires. As a result, a standardised and structured digital modelling strategy is proposed to improve results. This method entails using BIM estimating software such as TocomaniLink, which can connect directly to BIM design tools, for instance, Revit, via plug-ins [27].

Quantity surveyors can create measurement procedures to generate essential quantities for the cost estimate automatically from the underlying model and then map the cost data to the applicable construction components [27, 29]. The objects can be linked in the model to assemblies or items in the estimating programme or from an external database in real-time. In this situation, BIM design technologies are primarily used to enhance cost estimating procedures by providing model visualisation. This method employs specialised quantity take-off software like Autodesk, Vico Office, and Exactal CostX, which transports BIM models and embedded data from BIM design tools into their system.

These solutions can offer automated extraction and manual take-off features, similar to the previous approach. They can generate visual take-off diagrams when visualising models, allowing quantity surveyors to perform take-off building components using colours, cross-check take-off lists, and view which components have been included or not in the estimate [27, 29]. Quantity surveyors could benefit from this technique because they can work with familiar Quantity Taking-Off tools without needing a deep understanding of BIM design platforms.

3.3. Potential adoption of HBIM in quantity surveying practice

Conservation projects have become more complex and challenging to manage. Therefore, it is vital to relate the process of recording and conserving heritage buildings to the conservation and normal maintenance of structures to safeguard heritage buildings [28]. In the realm of heritage building conservation, regular maintenance entails a procedure that is connected to documentation and heritage building management. Throughout previous decade, many traditional surveying techniques have been used to document and describe these buildings. Following this, a solution that allows all accessible building data to be collected, compared, and shared, as well as future information on repair or restoration efforts, is a logical next step [30]. 3D terrestrial laser scanning and photogrammetry in documenting cultural heritage sites have become increasingly common [31]. Where previously there was only a sparse set of data, current systems can measure or quantify a large number of points per second clustered in the point cloud.

The point cloud data serves as the basis for rebuilding the geometry of the HBIM model. The user defines the elements manually and fits the primitives into the cloud of points. In libraries, the designed objects are predefined or generated by the user [32]. Since the manual effort is extensive, it proposes automated approaches for creating existing buildings using BIM models. The initiation phase in gathering information for heritage building documentation is to give topological data and content relationships on paper sheets, analytical software engines, and 3D laser scanning devices [33].

Survey techniques have gained popularity in recent years, particularly in the context of heritage buildings. Table 1 shows 3D data acquisition by surveying and employing well-structured 3D modelling techniques such as the image-based approach, the range-based approach, and a combination of both techniques. Most of this study revolves around their application to heritage documents. However, semi-automated methods with manual measurements are still preferred to generate complete, accurate, and detailed modelling [24].

Table 1. Review of high-definition surveying methodologies [24, 28, 30, 32].

Techniques		Description	Advantages	Disadvantages
Image-based methods	Image-based modelling	● Using images for the reconstruction of 3D models by photogrammetric survey ● Using models to pick up 3D object information from 2D images to recover 3D data by shape form shading, texture, and contour	● Widely used for geometric surfaces, precise terrain, and city modelling ● Provides both geometry and surface texture. ● High geometric accuracy without capturing all the finer geometric details	● Lack of details when compared with laser scanners technology
Image-based methods	Image-based	● Using images as modelling and rendering primitives when limited visualisation is required ● Relying on accurate camera positions or performing automatic stereo matching.	● Good for the generation of virtual views ● More realistic and faster rendering to simply the modelling task	● Does not include the generation of geometric 3D models, but it might be considered
Non-Image-based methods	Range based modelling	● More recent and familiar method of 3D data acquisition by using laser scanner technology. ● It can be airborne or terrestrial. However, the scanning principles and output from the scanning, which is point cloud data are the same ● It is required to make multiple scans from various locations which adjust to object size, shape, and occlusions	● Rapid and active technique to acquire point cloud describing all the 3D building's information down to millimetre details. ● The resulting model can be sliced through different planes to produce accurate plans and elevation ● Suitable for both expert and non-expert users	● Reliability and accuracy are affected by weather conditions, the object, and the operator's experience. ● Output needs post-processing for good recording quality ● Costly active sensor ● Difficulty in extracting the edges
Combination of image and range-based methods		● This combination overcomes the disadvantage of the previous methods because no single technique can efficiently provide the complete model. Thus, the rational solution is determined by image-based methods and details by laser scanning.	● Allowing the generation of complete and detailed 3D models efficiently and quickly	● More technical barriers and difficulties in extracting data during the HBIM process

4. Case Study Approach

A case study approach is adopted in this research to demonstrate the potential of HBIM using a 3D laser scanner in enhancing the estimation of heritage building conservation works by quantity surveyors. According to Yin [34], a case study can be defined as an approach that explores a current phenomenon within its actual context. The case study approach can be conducted using a single case study or multiple case studies. Johnston et al. [35] explained that an effective case study must comprise the followings: (1) begin with an assumption based on theoretical findings; (2) must be systematic and logical; and (3) must be evaluated individually.

Hence, the Hilltop Private School in Johor Bahru is one of the historic buildings chosen as the case study for this study. This building was built in the 1900s. Upon its completion, the building was used for residential purposes. However, since 1940, Hilltop Private School has adapted the building for use as a pre-school. Hilltop Private School was founded in 1940. Therefore, it is undeniably a heritage building, as the building has been around for decades. Furthermore, the double-storey home is planned with servant's quarters and annex structures, which the school has inventively used as classroom facilities. The colonial architecture greatly influenced the design concept of the building as those features can be seen in the use of classical ionic columns, decorative plaster for both external and internal walls, and the design of the windows and doors [36].

4.1. Equipment and workflow

The building was scanned using the Faro Focus 3D X 330, a 3D terrestrial laser scanner capable of precise measurement and documentation for the case study. It provides detailed 3D photographs of surrounding and geometries in a single scan configuration instead of photogrammetry. The laser scanner has a vertical and horizontal field of vision of 360. Hence, it can capture a complete panoramic view. The scanner scans at a rate of up to 976,000 times per second. The station positions were marked before the scanning to ensure a proper overlap between these scan stations.

Furthermore, reference spheres were used to ensure high-quality scanning. To capture all the essential data to produce an as-built BIM model, the building was scanned from various scan-station positions, covering both external and interior architectural features such as roof structures, walls, floors, windows and doors, and columns. Figure 1 depicts the case study flow of equipment. Figure 2 is the case study workflow applied in this study.

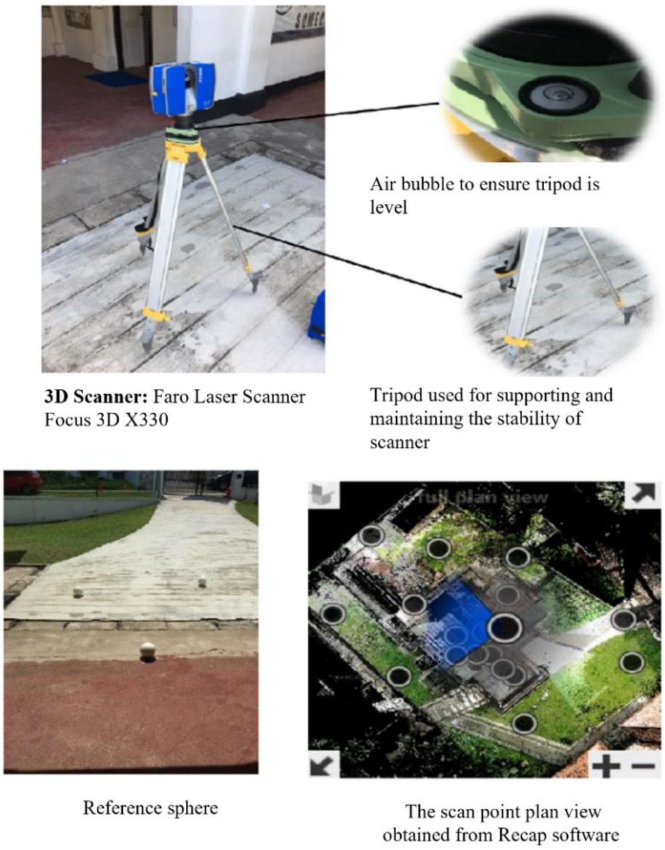

Fig. 1. The equipment and setting out during the data acquisition phase.

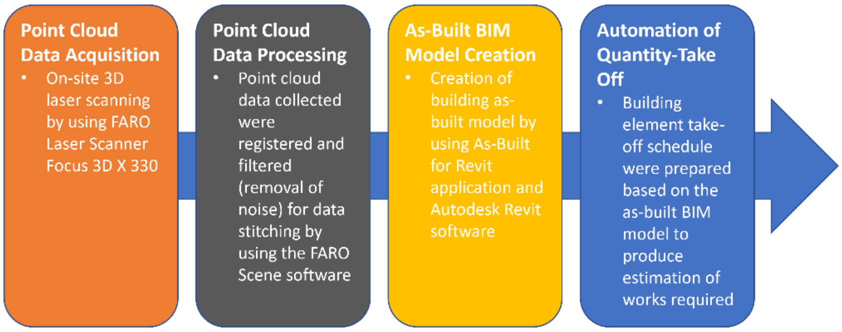

Fig. 2. The flow of the case study, adapted from [26, 28].

4.2. The HBIM Process

4.2.1. Data acquisition

Before the scanning procedure, a walkthrough survey of the building was undertaken to establish the number of scan-stations required and their location simultaneously, ensuring a good overlap between them. The laser scanner must also be positioned so the laser beam can reach as many parts of the building as possible. These steps are critical since an erroneous laser scanner placement, and an insufficient number of scan stations may result in a lack of data and incomplete point cloud data. As a result, 19 designated scan-stations were included in this research to assure the correctness of the data obtained).

The laser scanner was installed on a levelled and solid tripod where the laser scanner reference spheres were positioned once the scan-stations were identified. The coordinate references inside the scanning data cloud are determined using these laser scanner reference spheres as a guideline. The scan resolution was selected, and the time for each scan was set to about 5-6 minutes. Figure 3 shows the on-site setting up process. The laser scanner was then moved to the second scan-station for the following scan after the first scan was completed. To create a rich 3D point cloud collection, 19 scans were conducted in various designated scan-stations.

Fig. 3. The setting up of laser scanner and placing of laser scanner reference spheres and the user interface of the 3D laser scanner.

4.2.2. Data processing

Before being employed to develop geometric drawings, the 3D point clouds acquired in the preceding stage must go through a pre-processing phase. During this phase, the scanned points were merged into a single point cloud in a shared coordinate system. Through the steps of (1) Point Cloud Registration; and (2) Data Processing, BIM software was required to work with the 8.03 GB of raw 3D point cloud data.

(1) Point Cloud Registration: The 3D point clouds acquired from the various scan stations are recorded and saved in a coordinate system related to the scanner in this procedure. The reference of the scanned object in a coordinate project system or combining two or more-point clouds is acquired from various scan sites. This is accomplished by employing tie and control points that are either object features (e.g., corners) or specific targets (e.g., spheres, flat targets with high reflectivity). In this situation, spheres were employed in the processing stage of the point cloud. If two or more scans were performed at distinct scan stations, the scan coordinate system was only identified after each scan.

Therefore, it is necessary to determine the spatial relationship through a process known as data registration. Furthermore, Scene Software is used to register point clouds, normally done using customised targets, overlapping point clouds, or a mix of the two. Alternatively, registration through cloud matching is accomplished by picking a pair of partially overlapping scans and employing appropriate algorithms to align one scan with the other. The FARO Focus 3D X 330 high-resolution 3D laser scanner was employed in this study. The SCENE software imported the scanned point-cloud data, enabling the automatic registration function. As a result, 19 scanned point-cloud data were successfully merged into a similar coordinate system.

(2) Data Processing: The acceptability parameters were pre-determined in this process to determine the viability of the obtained point cloud data. Cleaning and eliminating erroneous data or artefacts, such as scanning through object reflections, are part of the data processing stage. During the data processing stage, these incorrect points might be removed. Furthermore, with this strategy, incorrect points arising from multiple reflections can be removed. Following removing the incorrect points, the colourisation option was chosen to apply the images to the point cloud data, as shown in Fig. 4.

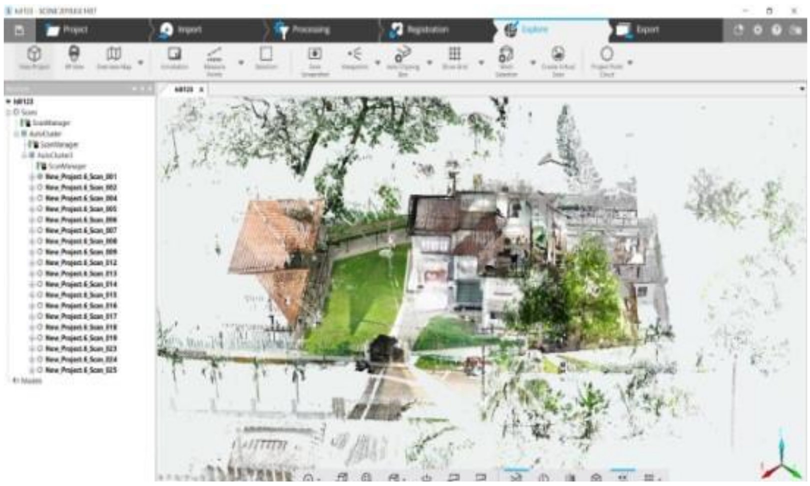

Fig. 4. The completed point-cloud model in FARO scene.

4.2.3. As-Built BIM model creation

The geometric modelling of Hilltop Private School's as-built BIM was started once the registered 3D point cloud had been imported into the Autodesk Revit software. The as-built BIM creation of the building is composed of three sub-procedures which were (1) Preparing the project; (2) Preparation of the point cloud; and (3) Geometric modelling, which will be explained as follows:

(1) Preparing the project: To use the scanned data from the scans in other compatible BIM software such as Autodesk Revit for the geometric modelling process, the registered and filtered point clouds must be converted into ReCap format (RCP or RCS) before the point cloud data exportation. A total of 3 hours was required to convert the point clouds into RCP format, and the imported point clouds in the Revit (as shown in Fig. 5)

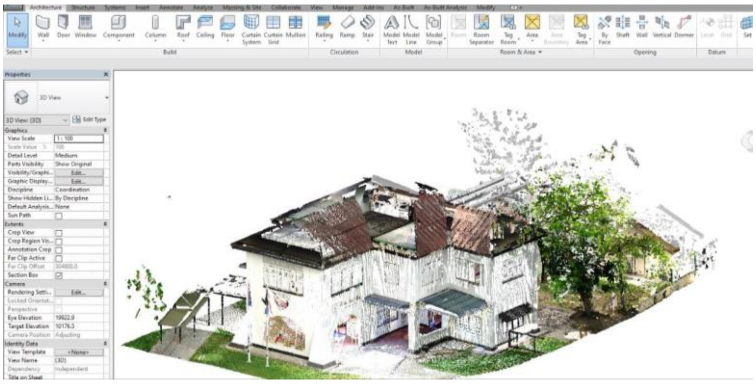

Fig. 5. The imported point cloud in the Autodesk Revit software.

(2) Preparation of the point cloud: While Autodesk Revit currently provides simple methods for constructing and customising building models from point clouds, as-built software for Revit expands these capabilities by allowing users to create and customise components and construction aids in the point cloud. After having the datums such as the floor levels determined as shown in Fig. 6, as-built software for Revit was used to prepare the point cloud to create pre-computed images on the floor plan as shown in Fig. 7. The previous point cloud in the floor plan was then replaced by the pre-computed image which enhanced the visibility of the point cloud for the geometric modelling process.

(3) Geometric modelling: This sub-procedure demonstrates ways of as-built BIM for the building can be created from the point cloud data. It should be noted that the materials for the building components created were assumed to be made of default type in the existing Revit library as the focus was on geometric modelling. Moreover, in consideration of both the huge sizes and the excessive deterioration of the building, the level of detail in the as-built BIM was reflected by modelling only some of the structural-related components (external walls, internal walls, floors, columns, ceiling, roof, windows, and doors excluding staircases and furniture). Furthermore, this building is relatively more geometric complex than modern existing buildings with details, ornaments, non-parallel walls and walls of varying thickness which makes the modelling process difficult. To solve such

complexities the As-built for Revit plugin tools can be used to provide precise wall fittings and alignment to the building’s point cloud as shown in Fig. 8.

Fig. 6. The datum such as the floor levels and grid was determined and shown in the section view.

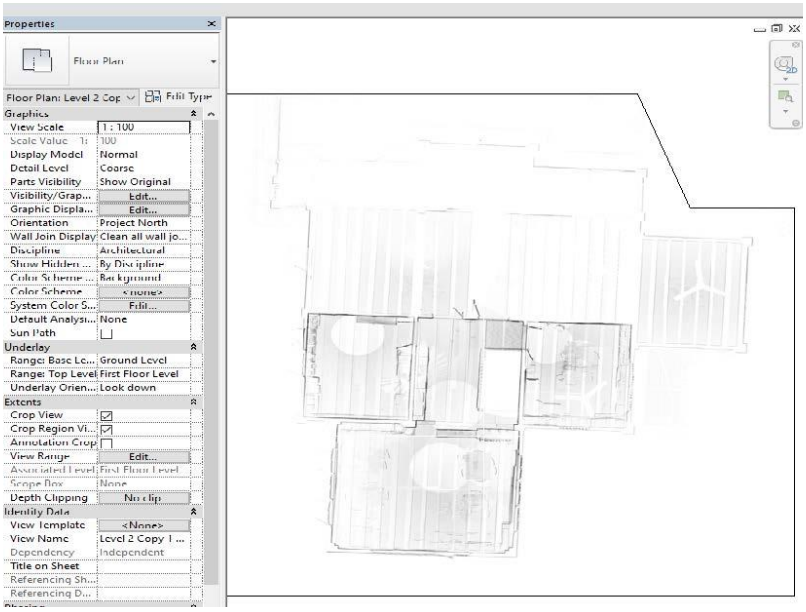

Fig. 7. The creation of a pre-computed image on the floor plan.

(4) After completing the as-built BIM creation of the building, 3D visualisation purposes were performed and shown in Fig. 9. The as-built BIM model of the building was made using a 3D laser scanner and SCENE software, and it is thought that the model is realistic and in compliance with building's actual condition. The next section demonstrates ways automated quantity take-off can be performed on the created building as-built BIM model.

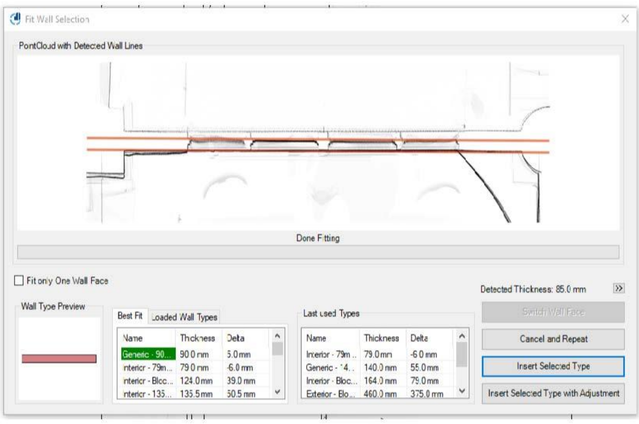

Fig. 8. As-built for Revit software provide fit wall function where detected the best fit for wall lines.

Fig. 9. The as-built BIM model of the building.

4.2.4. Automation of quantity take-off

The building element take-off schedules for each selected building element were developed after the completion of the BIM model to display more detail about the assembly of a component with the sub-components or materials indicated. Revit will automatically calculate the number, area, volume, and length of the selected building elements before displaying the quantity in take-off schedules. The roof, wall, column, doors and windows, flooring, wall finishes, and ceiling finishes, as proposed by [16], are among the building conservation features that will be extracted. The following is the method for calculating heritage building conservation based on the case study as-built BIM created by 3D laser scanning:

(1) Creation of building element take-off schedule: The completed as-built BIM allows the user to extract any required building information from it for different purposes such as space planning, costing for materials and scheduling of building elements.

(2) Selection of attributes: After selecting the Material Take-off option in Revit, the floor category was selected to extract the exact and accurate area for the conservation process in Option 1. The next step involves selecting building element

attributes in the Material Take-off Properties tab. The area category was selected to obtain the total surface area of flooring for the replacement works as mentioned in Option 1.

(3) Completion of building element take-off schedule: Revit was used to extract the quantities of building elements from the as-built BIM model with the quantity take-off displayed in the Floor Material Take-off, as shown in Fig. 7, upon selecting the desired building element category with its relevant attributes such as the area, family, etc. The data was then rounded to estimate the precise area of the floor finishes. Following that, the extracted quantities were calculated automatically by Revit without any human intervention, achieving the goal of quantity take-off automation. Table 2 shows the extracted quantities of walls, columns, doors and windows, flooring, wall finishes, and ceiling finishes that can be utilised for conservation and restoration.

Table 2. Surface areas of building components.

Items	Quantity (㎡)
External wall	653 ㎡
Internal Wall	269 ㎡
Flooring	362 ㎡
External wall finishes	1306 ㎡
Internal wall finishes	538 ㎡
Ceiling Finishes	382 ㎡
Roof	397 ㎡

5. Discussion of Findings

Hilltop Private School was a suitable sample for this study as it demonstrates the capabilities of HBIM using 3D laser scanning. The building has the following qualities; (1) Historical significance, (2) Decent design and architectural values, (3) Long history, as it is over 80 years old, (4) Unique cultural heritage, as the design concept was heavily influenced by Western architecture, and, most importantly, (5) The as-built drawings and design specifications of this building are missing, leaving QS with no guidance for estimation. The lack of references in an as-built drawing necessitates using a building condition survey to duplicate the drawings. The result of data collection to automation of quantity take-off has been demonstrated to be beneficial due to the elimination of laborious stages.

These traditional working methods have been proven to be inefficient, time-consuming, and prone to errors. A 3D laser scanner and BIM software can eliminate and simplify these time-consuming activities. Furthermore, the application of 3D laser scanning technology has resulted in speedy, safe, and non-invasive data collecting, as demonstrated in this study. The 3D laser scanner is simple to use, and lack of detail owing to inexperience is avoided during the survey. The acquired point cloud data was then processed off-site for quantity take-off automation. This lowers the time necessary to prepare as-built drawings and building element take-off for the building's conservation and restoration. Using the traditional taking-off method, it is common for quantity surveyors to spend substantial time reviewing and understanding 2D drawings, extract quantities manually and transfer it into software to format the quantities accordingly into the required Bills of Quantities.

It requires long working hours and effort to be produced the Bills of Quantities with an elevated risk of human errors.

In this research, these tedious processes have been reduced using automation of quantities take-off from the 3D model produced. The 3D BIM model is developed based on the actual condition of the building on site. Without the need to be physically at the site, QS can visualize the building remotely or even for enhanced visualisation. The quantity surveyors can use digital technologies, such as Virtual Reality (VR), to enhance their visualisation and understanding of the building they are quantifying. Quantities take-off for heritage buildings can be troublesome as it is typical that this building does not come with any representation in the form of a drawing, or even if the drawing is available, it does not represent the actual condition of the building. Hence, the quantities that the quantity surveyors have extracted to conserve the heritage building might not be accurate, affecting the overall cost of the conservation work for that building. In this research, the automation of quantities take-off was conducted straight from the 3D model produced using the Scan-to-BIM approach allows for more accurate take-off.

Concerning this, if there are any changes in the specification and quantities of the conservation works, it can simply be reflected without the need to go through tedious processes of quantities take-off again. This is similar to the benefits of using BIM in quantities take-off, but the difference is in the context of the project and the 3D model itself. Furthermore, in this research, it has been demonstrated the quantities take-off can be conducted using Autodesk Revit via scheduling. Although this research does not fully demonstrate, the 3D model developed based on the Scan-to-BIM approach can be used in other software applications, including Cubicost, Vico Office, CostX and other similar quantities take-off software. Hence, this shows the interoperability of the developed model with other software that could help in better quantities take-off. In addition, using this software, the quantities take-off can be done while complying with the required standard method of measurements before Bills of Quantities are produced accordingly.

Accessibility: Firstly, as mentioned in the issues associated with conventional measurement, it is found that there are many obstructions and obstacles within and around the building. Therefore, with the utilisation of the 3D laser scanner, the mentioned difficulties were addressed. The laser scanner covers a range of 360° views in the vertical direction and 360° views in the horizontal direction. This enables the laser scanner to cover the areas that cannot access through the voids and the openings of the building from different scan stations. As such, the point cloud data will be collected. Secondly, the laser scanner adopts phase shift technology that emits constant waves of infrared lights of varying lengths outward from the scanner. When the infrared light strikes an object, it is reflected in the scanner, hence no physical contact is made with the building's fabrics. This non-invasive scanning method ensures that no physical damage to the building occurs.

Timescale: With the time and logistic limitation, this becomes an issue for remeasurement. If manual remeasurement is to be performed on the building, it is believed that it will be difficult and time-consuming as the building is large and there are many unique details on building elements such as columns, windows, and doors. Hence, the 3D laser scanner is utilised in performing remeasurement. It is claimed to be ten times quicker in measuring building elements than manual remeasurement [37]. This will decrease field time and reduce rework efforts while increasing the visibility, accuracy, and understanding of building data collected. For instance, six (6) working hours were used to complete the 3D data acquisition process, which is significantly quicker than implementing the manual remeasurement method. Therefore, it is evident that HBIM could become a feasible method compared to conventional remeasurement.

Experience: Conservation of heritage buildings is conducted with different approaches compared to new building construction, and it is a relatively new practice in Malaysia as opposed to other countries [13]. Moreover, there is limited research on heritage building conservation, particularly on the costing aspects. The lack of research and limited understanding of QS towards heritage building conservation placed a great challenge which makes the data collection of building elements difficult to further proceed with the production of accurate cost estimation. Furthermore, with the complexity of the historic building, as they are full of details, ornaments, non-parallel walls and walls of varying thickness have made the geometric modelling process quite difficult using the available technology. This is also in agreement with [6], as the decision on the degree of model complexity and simplicity has to be undertaken to determine the suitability of the conservation purpose. This study also revealed that experience plays a vital role in conserving heritage buildings as well as the lack of understanding of conservation standard principles and guidelines on heritage building conservation projects.

However, in general, using a 3D laser scanner for data acquisition addressed the abovementioned issues. The possibility of missing details due to a lack of knowledge in heritage building conservation is minimal when surveying with a 3D laser scanner. The 3D laser scanner can capture all the necessary information while maintaining the quality and authenticity of the heritage building. The data collected were then subjected to an off-site process, which provides an option of keeping or deleting the point-cloud data collected. Furthermore, the laser scanner is portable and easy to use, with a user-friendly interface that makes it easy for non-surveying users to use.

6. Conclusion and Recommendations

Generally, studies appear to focus only on deploying as-built BIM rather than formulating cost estimates for conserving heritage buildings. The QS's capacity to apply heritage building conservation technical expertise is still unknown. It is unclear whether Malaysia will have a systematic framework or guidelines for developing cost estimates for heritage building conservation. Furthermore, the procedure and framework for estimating the cost of heritage building conservation are yet to be defined using the 3D BIM model generated by 3D laser scanning. Hence, exploring the potential of QS professional practises in heritage building conservation on the Heritage BIM platform with a 3D laser scanner would help promote a positive image of the profession. This study emphasises how 3D laser scanning technology results in rapid, safe, and non-invasive data collection.

Adopting HBIM in cost estimation could improve input information and quantity surveyor skills and comprehension, resulting in more accurate cost estimates. This research also adds to the current knowledge about BIM implementation and the dependability of cost estimates. It highlights the parts of BIM improved information that has the potential to improve quantity surveying practice. The Scan-to-BIM approach has proven to be convenient when details are lacking due to inexperience or faulty drawings during the survey. The acquired point cloud data is then processed off-site for quantity take-off automation, decreasing the time to generate as-built drawings and produce building element take-off for conservation.

The proposed approaches offer a potential solution to the concerns above by automating laborious processes, allowing QS to focus on providing additional value-added services to clients rather than spending most of their time performing traditional remeasurements and quantifications. BIM's ability to automate measurement is its most important feature from the perspective of a QS, and it certainly speeds up the traditional estimating process. HBIM provides a more effective operational solution for quantity surveyors for cost estimation due to its ability to link essential quantities and cost information to the digital building model and update them promptly to design changes. Finally, as BIM and HBIM adoption in Malaysia are still relatively low and limited in Malaysia, future research needs to explore and develop HBIM for cost estimation framework and workflow application which could be applied to existing Malaysian heritage conservation guidelines. This would promote the adaptation of best and innovative practices in heritage building conservation as well as strengthen the image of the Malaysian built environment.

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