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EXPLORING DIGITAL DOCUMENTATION FOR SHOPHOUSES IN SINGAPORE

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KEY WORDS: 3D, Photogrammetry, LiDAR, SLAM, shophouse, UAV, digital documentation

ABSTRACT:

Conservation of cultural heritage involves beyond repairing and maintaining the structures. Prelude to any conservation should be a comprehensive documentation, recording, historical study and condition assessment. Then only should the repair and restoration be considered. Damages and deterioration of cultural heritage are unpredictable in disasters. Wear and tear may some time lead to sudden catastrophic failures. As such documentation and recording of cultural heritage should be ongoing exercises. The information is also useful for in-depth understanding and research purposes.

Documentation methods have developed over time with the progress in information technology and computing. Analog documentation methods have given way to digital documentation which is faster and more comprehensive. In this study, four digital documentation methods have been evaluated to explore their capabilities for documentation of a heritage shophouse; a range of unique architecture constructed from 1800s to 1900s found commonly in cities around Southeast Asia. The data was produced into 3D models and comparisons between the different methods were made. The strengths and weaknesses of each method as well as the quality of the outputs were evaluated. The digital 3D model will be useful for subsequent conservation process. This information can also be developed into repository of architectural features and also for use in HBIM system or parametric architectural components database system. There are, however, obstacles and challenges to development and implementation of such as system.

1. INTRODUCTION

1.1 Historical Significance of Shophouse

Modernization and development in Singapore took place in a feverish manner in the 60s-80s, resulting in loss of traditional landscape (Savage, 2001). The shophouse is a vernacular building with a narrow frontage of 20 feet or less, depth of 60 – 70 feet built in terrace, thus without ventilation at the side. The shophouse is significant and common in South East Asia, built between 1840s to 1960s. Initially they are used for residential quarters on the upper floors and business use on the ground floor. Those constructed in later years include those purely for residential purpose. There are no official historical records of the number of shophouses in Singapore except for a survey in 1980, which reported the number of shophouses in and around city (central) area to be approximately 15,000 (Savage, 2001). Recently there are approximately 6000 shophouses left, mostly around central (city) area and have been earmarked for conservation. Their heritage status and limited supply have catapulted the demand; thus, prices of these houses are beyond affordability of most common folks (Leong, 2021). Refer to Figure 1 for typical view of shophouses. More beautifully restored shophouses can be seen in Singapore Shophouse (Davidson, 2010).

A field survey in 1996 has shown that 39% of shophouses in six districts were either occupied, unrestored or undergoing restoration and 14% are vacant/dilapidated. Most of the shophouses have been altered for retailing, residential and commercial uses. The conservation policies by the Urban Redevelopment Authority (URA) of Singapore have been successful and quite effective in retaining the ethnic-based activities in historical districts, retaining the original fabric and restoring the historical and architectural significance (Sim, 1996).

Figure 1. Typical of internal of shophouse adapted as a museum and (right) front "five-foot path" forming a shaded walkway in-front of the shophouses.

1.2 Shophouse

Locally, a shophouse is known in Chinese term as "店屋dian wu" which means "shop" (Yeoh, 2010) and "house" and in Malay as "rumah kedai" means "house shop" (Elnokaly & Wong, 2014). The shophouses are a unique form of construction in towns and cities of Southeast Asia, as they consist of spaces for business on the lower floor and accommodation on the upper levels (Yeoh, 2010). Many shophouses have been adapted for reuse, protected, and conserved. (Li, 2007; Yung, et al., 2014; Aldy, 2020; Wang & Jia, 2015; Zubir, et al., 2018; Aranha, 2013; Eddy, et al., 2020; Yam & Ju, 2016) There are a handful of shophouse typologies which have developed over time (Figure 2). Due to urban development in the city centre, some shophouses have been demolished due to the high cost of restoration and land scarcity (Savage, 2001); many of these houses have been converted for reuse as hotels, restaurants and other businesses. With the reduction in their number and limited supply, these shophouses have become good investments. Unfortunately, this has also driven away many traditional trades' practitioners and businesses.

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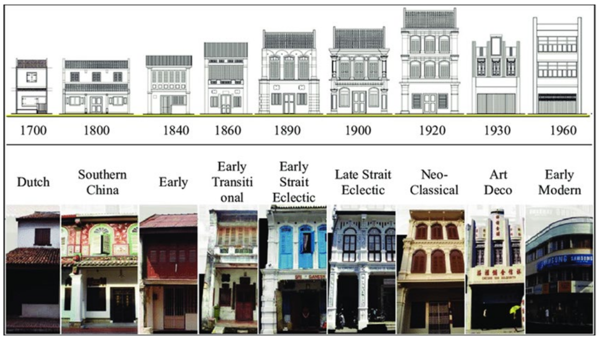


Figure 2. Typical shophouse typology (Savage, 2001)

2. METHODS AND DESCRIPTIONS

2.1 Overview

Data acquisition was carried out using four techniques and equipment, namely: Matterport Pro2 3D Camera; GeoSLAM ZEB Horizon Mobile LiDAR; Leica RTC360 3D Terrestrial Laser Scanner and; Flyability Elios2 Indoor Drone. These were the best equipment available for the evaluations, during this project. In subsequent part of this report, these shall be referred to as Matterport, ZEB, RTC360 and Elios2. Acquisition was carried out over different days due to availability, access, and time constraints. Aside from the proprietary software for each equipment, the data captured were downloaded and processed to produce 3D models using photogrammetry software, ContextCapture®®, by Bentley, for processing of mesh and qualitative comparisons. The hardware used are briefly described below.

2.2 Terrestrial Photogrammetry: Matterport Pro2

Matterport Pro2, a form of photogrammetry tool with SLAM (simultaneous localization and mapping) technology, works by capturing 360° (left-right) x 300° (vertical) field of view, 134 megapixels panoramic images and converting into 3D spaces. The system uses a structured light (infrared) 3D sensor. The camera is mounted on a tripod and an internal motorized mechanism rotates to scan the surrounding environment. It estimates interior dimensions and captures objects, colours and textures by repeated scanning from multiple positions within the mapping area. Systematic errors from the system are several centimetres and preliminary calibration should be carried out for better dimensional output (Shults, et al.). The processed data could be downloaded as point cloud and processed with third-party software.

Forty-five scans were carried out in the shophouse and scanning took approximately 5 hours. The equipment was relatively easy to operate and operators can be trained to use the equipment within an hour. The tripod must be placed on a stable and flat surface; thus, slopes and steps are a challenge.

2.3 Mobile LiDAR scanner: GeoSLAM ZEB Horizon

GeoSLAM ZEB Horizon© is a LiDAR based-SLAM device, capturing 300,000 points per second up to 100m range, with up to 3 cm accuracy whilst on the move. Firefly Action Camera attached to the scanner, records video simultaneously and used for colorizing the point cloud. The point cloud could be exported for drawings using proprietary software, GeoSLAM Draw©. The point cloud was used to generate mesh, drawings and 3D model by exporting to other third-party CAD software.

2.4 Terrestrial Laser Scanner: Leica RTC360

Leica RTC360 is also a LiDAR scanner which captures two million points per second and range from 0.5m to 130m with accuracy of 1.9 mm at 10m range. This method has been reported to have good accuracy. The data was imported to a proprietary 3D point cloud processing software, Cyclone, for registration, colouring and cleaning and to generate a 3D mesh on a third-party software. Scanning was carried out with the scanner mounted on tripod.

Scanning was carried out from multiple locations within the shophouse and took approximately 6 hours, The equipment usage overall was easy to learn.

2.5 Photogrammetry on Unmanned Aerial Vehicle (UAV): Flyabilty Elios2 indoor drone

Flyability Elios2 was designed specifically for GPS-free environment, underground and indoor and suitable for confined space. It has 10,000 lumens oblique lighting in addition to an infrared camera, making it suitable for dark spaces.

Data was captured in video and photo formats with a 12 MP camera and viewed through proprietary software, Inspector 3.0®, wherein video frames were extracted and subsequently processed through photogrammetry software into 3D mesh models. Its specified resolution is 0.18mm/pixel.

Data capturing during the flight takes approximately 2 hours for the house. This method requires experienced UAV operators to capture data.

2.6 ContextCapture® by Bentley

ContextCapture® produces 3D models using ordinary photographs. As such it can be used for objects of sizes from a few centimetres to kilometres. The precision of the resulting 3D model is only limited by the image resolution of the photographs. For processing, the default settings for the software were used.

2.7 Layout of Shophouse

The site is a 3-storey shophouse, the ground floor is divided into approximately 3 sections from front to back (Figure 3). The entrance of the house starts with the five-foot way which has a door leading into the forecourt. Scanning was carried out within the inner part of the three storey shophouse.

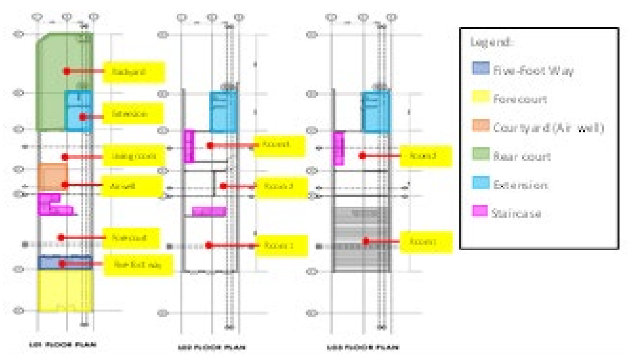


Figure 3. Layout of the Shophouse. The entrance is on the 1st floor through five-foot-way.

3. COMPARATIVE ANALYSIS

3.1 Outline

Comparisons of the different methods were carried out qualitatively after data were downloaded and processed. Where necessary, the data would first be processed using proprietary software from the hardware to generate the point cloud. Subsequently, 3D mesh and model were generated using ContextCapture®®. Typical workflow for the processing includes cleaning, filtering, meshing and rendering (texturing).

The data from 3D scanning and photogrammetry were processed and output in several ways.

A 3D **point cloud** is a collection of data points analogous to the real world in three dimensions. Each point is defined by its own position and (sometimes) colour. The points can then be rendered as pixels to create a highly accurate 3D model of the object. However, the device used to collect the data has different accuracies which will lead to some deviation in the points generated. When generating point clouds, spatial decimation affects consistency and smoothness of the point cloud.

A 3D **mesh** is constructed from the point cloud, consisting of polygons connected from the points in the point cloud which defines the shape with height, width and depth. On flat surfaces such as wall, the number of triangles is small, and the size is big to depict a flat surface. At corners and uneven surfaces, there are many smaller triangles.

When generating a **3D model**, the accuracy of the model depends on the hardware's accuracy of the scanner and how the photos were taken. The point clouds could be rendered with photographs taken together during the scan or separately.

3.2 Features for comparison

The qualitative comparison was made on the overall indoor model as well as selected features such as balustrades, mural, timber joists and tiled surface. These features were selected based on their significance and difficulty in obtaining clear output from the scanning. It is known that thin and flat features pose problem to scanning. Comparisons were made based on the costs, convenience and output obtained.

3.3 Processing

The data collected from the different devices were processed with ContextCapture®®[1] into 3D mesh model for viewing. It is obvious that the data with more points displayed a clearer and more detailed model of the house. As there are a larger number of points in the same frame, the point cloud density is higher and point cloud spacing will be smaller allowing more specific details to be seen.

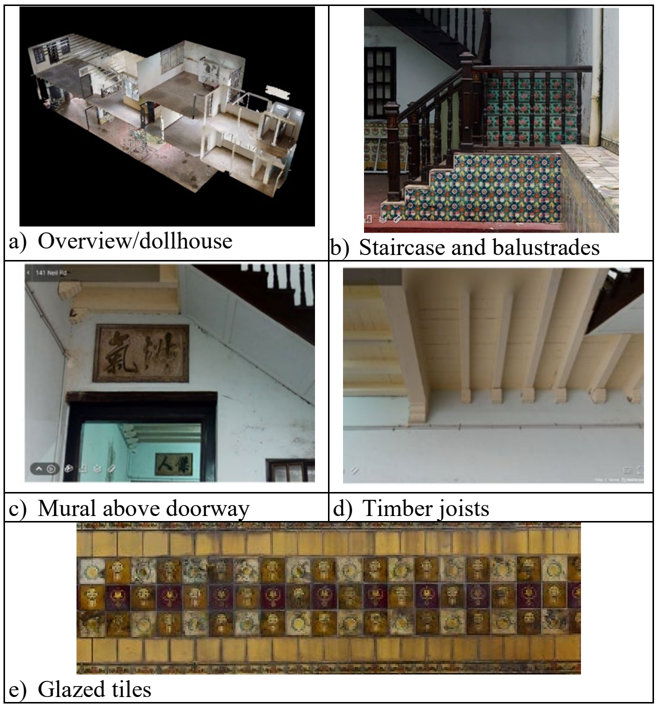
Photogrammetry techniques, Matterport and Elios2, are affected by lighting conditions during data capturing. The results from the different techniques are presented below.

4. RESULTS

4.1 Terrestrial Photogrammetry: Matterport Pro2

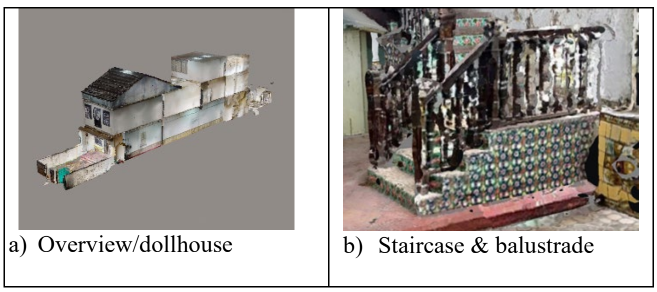
A section of the scanned 3D output from Matterport, typically called a dollhouse, is shown in Figure 4 below. Matterport produces clear visual photographs due to the 134-megapixel photographic quality. This makes it suitable for visual inspection recording. The output from Matterport cloud server (3D space) is as shown in Figure 4. The point cloud from Matterport server can be downloaded for viewing and processing on third party software. In this study, the data is processed using ContextCapture® photogrammetry software and the output (3D model) is shown in Figure 5. It is observed that the output on the server has a better visual quality than the one processed via external software, comparing Figure 4 to Figure 5. This is likely due to how the point cloud was extracted as it appears that the point cloud was subsampled.

The Matterport cloud server storage space is on subscription basis and the point cloud could not be viewed from the Matterport server. While viewing from the Matterport server, the 3D space is clear and realistic but the viewing angles were limited as it only shows the 360-panorama photograph that was taken where the scanner was placed. Details could be observed clearly. However, when viewed at an angle. due to its panoramic photograph, the space appears to be out of proportion. Viewing the point cloud processed in ContextCapture®, the mural above doorway on 3D space is clear (Figure 5).



a) Overview/dollhouse
b) Staircase and balustrades
c) Mural above doorway
d) Timber joists
e) Glazed tiles

Figure 4 Output from Matterport Pro2 viewed from cloud server showing overview, staircase, doorway, timber joists and glazed tiles in panoramic photos.



a) Overview/dollhouse
b) Staircase & balustrade

[1] ContextCapture® is a software by Bentley

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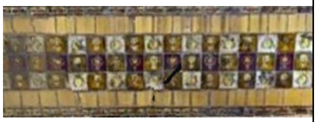
c) Mural above doorway

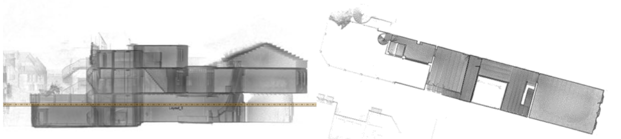


d) Glazed tiles

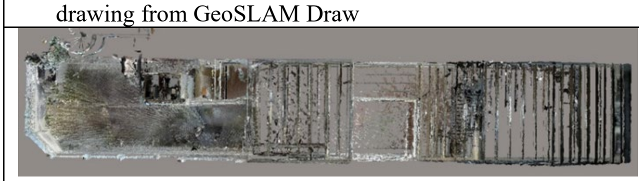
Figure 5. Downloaded data from Matterport as point cloud and processed using ContextCapture®® to produce mesh model

4.2 Mobile LiDAR scanner: GeoSLAM ZEB Horizon

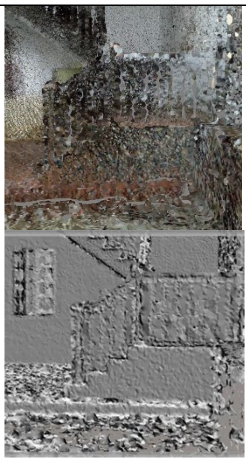
A section of the point cloud output from ZEB is shown in Figure 6. The point cloud data (Figure 6a) is very clear and clean for sectioning and dimensional drawings; however, the visual output (Figure 6(c-f)) is poor due to noise in the cloud. When showing the untextured mesh, it could be noted that the geometry of the balustrades and murals were not clearly captured. Similarly, the models of the ceiling and timber joists were not clearly captured.



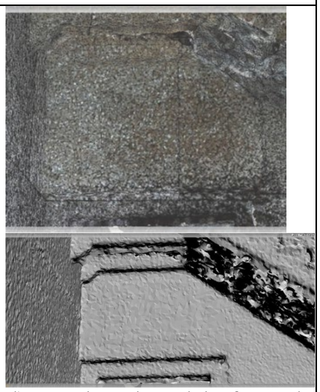
a) Point cloud data is clean and suitable for dimensional drawing from GeoSLAM Draw



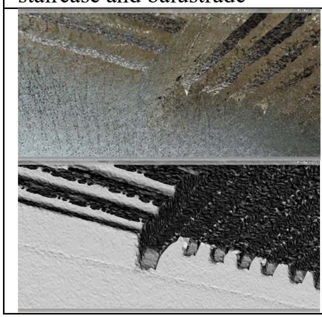
b) Plan view of the colorized point cloud



c) Mesh and model of staircase and balustrade



d) Mesh and model of mural above doorway



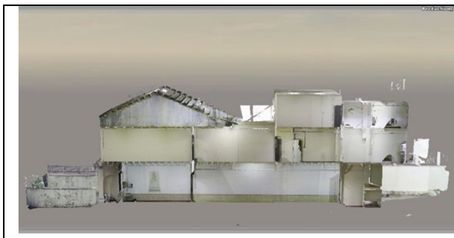
f) Glazed tiles

e) Timber joists

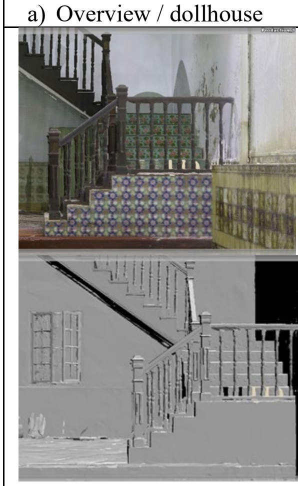
Figure 6. Point cloud results from ZEB and its comparison of colorized pointcloud along with the untextured mesh.

4.3 Terrestrial Laser Scanner: LeicaRTC360

A section of the point cloud output from RTC360 is shown in Figure 7. The colorized point cloud from RTC360 was processed on ContextCapture®. As the accuracy of the device was quite high the geometrical quality of features from RTC360 was the best among the methods evaluated. From the untextured mesh, it could be observed that the fine features and murals were well captured clearly. Similarly, the ceiling timber joists are also well defined with minimal noise.



a) Overview / dollhouse



b) (Above) Point cloud and (Below) model of staircase and balustrade

c) (Above) Point cloud and (Below) model of mural above doorway

d) (Above) Point cloud and (below) model of joists

e) Point cloud of glazed tiles

Figure 7. Point cloud output from Leica RTC360 processed on ContextCapture®®. The visual data is relatively clear. Internal camera captures video which is used to colour the point cloud. The grey point cloud shows the geometry of the various features captured. The quality of the model from RTC 360 is the best among the techniques evaluated.

4.4 Photogrammetry on Unmanned Aerial Vehicle (UAV): Flyabilty Elios2 indoor drone

Elios2 captures videos during the flight. The pilot is able to manoeuvre around and close to desired locations. This requires experience and certified drone pilots to capture good quality video. Photographs were extracted from the video and processed with photogrammetry software, ContextCapture®®. The visual photographic output is relatively clean. The model of balustrades, murals and timber joists are relatively clear. However, the geometry, especially flat surfaces, are affected by the lighting condition and shadow. (Figure 8)

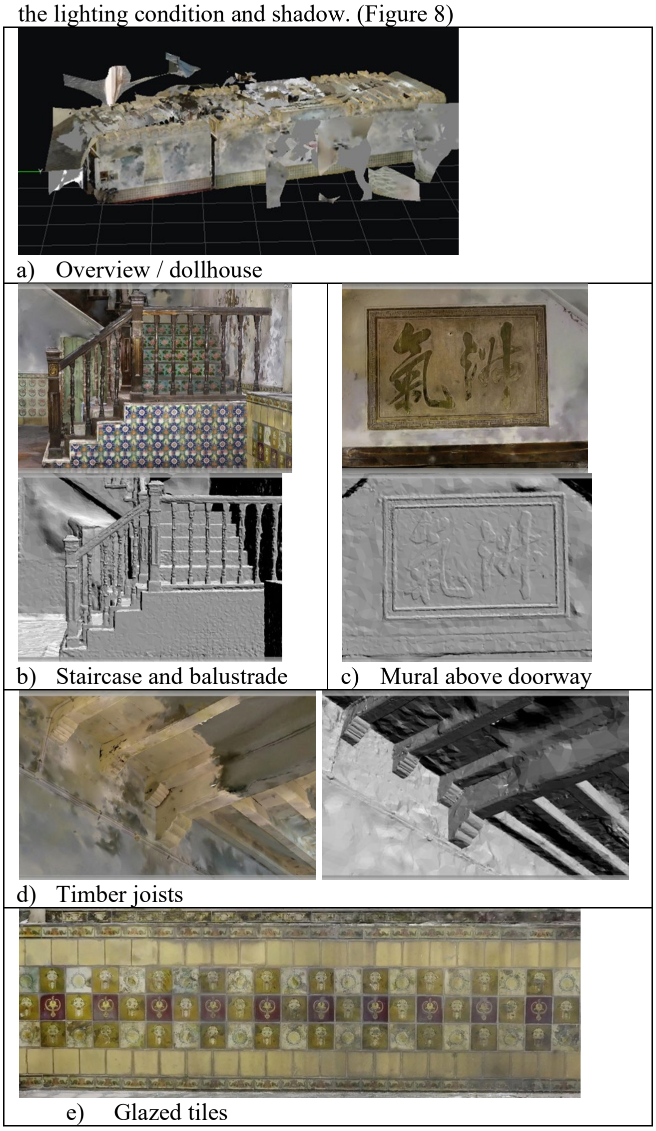


Figure 8. Point cloud results from Elios2 and its comparison of colorized pointcloud along with the untextured mesh.

4.5 Comparison of different techniques

Besides the quality of the output, other factors of concerned are also compared, such as operations, time taken for data capturing, file size, processing time and cost as in Table 1 below.

Static methods, namely Matterport and RTC360, which are mounted on tripod take longer time as scanning are required from each location. Flat and stable surfaces for placement of the tripod are required to prevent any error in the data capturing. Small and hidden spaces would require additional scans to ensure the data is captured. File size affects the processing time and hardware cost. Processing of data from these equipment is extensive and intensive. A standard desktop computer may not have adequate processing capability.

Processing time using ContextCapture®® to generate the 3D models are compared. As anticipated, the method with the largest file size required the longest time for data processing. The parameters are tabulated in Table 1.

The hardware cost is estimated on prices in Singapore. It is obvious that terrestrial LiDAR RTC360 is the highest cost, followed by static LiDAR ZEB. Photogrammetry method is generally lower in cost. The cost of Elios 2 is contributed drastically by the cost of the drone, which has the capability to fly without GPS and with crash protection.

Parameter	Matterport (static)	GeoSLAM Zeb Horizon (mobile)	Leica RTC360 (static)	Flyability Elios 2 (mobile)
Time taken for data capture	5 hours	30 mins	6 hours	2 hours
File size (kByte)	Not available	823,199	25,503,791	23,767,430
Time Taken to generate model (hrs)	0.3	1.4	24.4	3.5
Cost (Hardware) SGD [1]	3,000/-	75,000/-	100,000	61,000
Recurring cost /Cost (Server) SGD	1000/year	None	None	None
Strength	Photo-realistic	Relatively clean point cloud for dimension drawings. Access to tight spaces. Speed.	Precision and accuracy	Photo-realistic
Weakness	Inaccurate model, perspective issue	Limited detection of small and thin features. Cost	Time consuming data collection and processing. Cost.	Require drone pilot. Cost

Table 1. Comparison table of the 4 methods

Generally, the accuracy of the model increases from Matterport to ZEB to Elios2 to RTC360. The details were captured accurately on RTC360 but the optical quality is low. Matterport generated a model with good visual quality when viewed on their server. To view the point cloud and model, the data were downloaded from the Matterport server and processed with ContextCapture®. However, the quality of these models is

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relatively poor as compared to the server. The reason is not known. Matterport data is thus best viewed on their server.

The point cloud from ZEB is suitable and easy to use for generating dimensioned drawing. This can be done through their proprietary software on Geo Hub. The model from ZEB is accurate on a large scale. However, on smaller architectural features, such as balustrade and mural, the features are not observed on the model. This is the limitation of this mobile LiDAR which is unable to detect depth or thickness variation of approximately less than 1cm.

The model from Elios2 is relatively poor. Only model of level 1 was generated although the flight was carried out at the three floors. One of the issues faced was combining data from the different levels. This could be attributed to the data captured at the various staircases or the accuracy of the positioning system. More work and evaluations will be required to determine the cause and combine the data from different levels.

Matterport produces most photorealistic output of the tiles, murals, balustrades and timber joists. 3D models from RTC360, as expected, is the cleanest and most accurate. Information (such as materials, defects etc) can be tagged onto the model conveniently on Matterport mode as in Figure 9. As such information such as conservation requirements for sensitive and significant features can be directly added onto the platform.

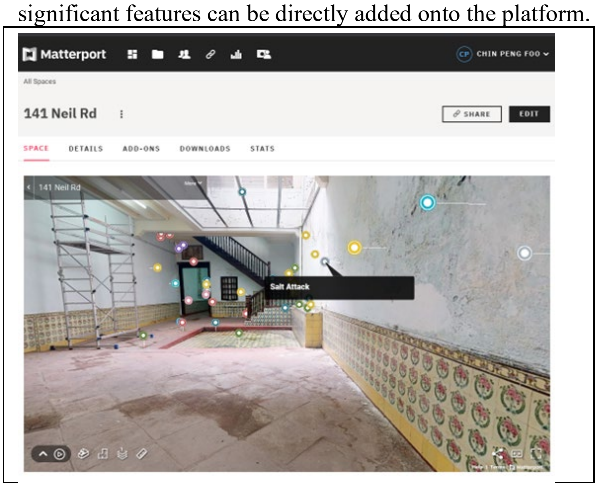

Figure 9. Inspection information can be tagged and included in Matterport

5. DISCUSSION

Overall, the Leica RTC360 produced the highest quality model in terms of geometric accuracy. The Elios2 produced the most realistic details of the house in terms of the architectural elements. Matterport produced the clearest photographs for visual inspection and recording of elements. ZEB Horizon produces relatively accurate model to be used for dimensional drawing of the house but not the decorative features. In terms of speed, the ZEB Horizon and Elios2 are time saving. The terrestrial LiDAR RTC360 proved to produce the most accurate point cloud as expected. However, this requires long processing time and the enormous data size requires more computing resources.

The use of the different devices to scan the area and methods to process the model produce models which vary in quality. The device's costs also differ significantly: Flyability Elios2: SGD61,000, Matterport: SGD3,000, GeoSLAM ZEB Horizon: SGD75,000 and Leica RTC360: SGD100,000[2]. Availability, resource, cost, output requirements and time are among the factors to be considered in selection of the method to be employed. To scan a large area (indoor) in a short amount of time, the drone should be used as it is capable of flying at fast speed, covering a large area in a short amount of time. Essentially one drone pilot is sufficient to operate the drone for scanning or operating the scanner. However, for safety reason typically one other personnel is preferred to be on a lookout.

The Leica RTC360 (terrestrial LiDAR) should be used when accurate dimension is required while ZEB may be used if a slightly less accurate dimension is acceptable. Furthermore, RTC360 takes a longer time to scan compared to the mobile techniques. Areas with many obscure locations or many obstructions may be scanned with a mobile device as it is easier to bring the device behind or over the obstacle rather making several static scans around, which increases the scanning time.

It is also to be noted that Matterport and Elios2 are limited to indoor scanning because these use infrared sensors which are affected by sunlight. If outdoor scanning is required, other scanners such as outdoor drone may be more suitable.

5.1 Challenges

Scanning will be difficult if the house is occupied. Furnishing will obstruct the views. Underside of roof structure may be blocked or hidden from view if covered by ceiling board. It is fortunate that the shophouse for this case is vacant and has no false ceiling.

Lighting condition and shadow around the shophouse also affect the quality of the videos and images captured, especially the photogrammetry methods. It is observed that the 3D models are distorted at locations where there are shadows and uneven lighting.

Despite the availability of 3D data capturing capability, there are still problems and challenges faced such as:

- Selection of methods to be used. As in the findings, no one technique can document the variety and range of features. Thus, for good visual quality and geometry, different methods are required to cover both large and small features.

- Data processing is time consuming. Processing hybrid data sources is still challenging for software and users.

- The sharing and viewing of final 3D model require users to be relatively cogent with the software. Virtual reality (VR) viewing platform and tool have been available for some time. However, 3D models have to undergo additional data processing to enable viewing through VR goggles.

In general, 3D scanning is relatively high cost and expertise familiar with both scanning techniques and built heritage are still not commonly found. Most heritage conservation practitioners are still relying on photography for recording and documentation. An expert in digital documentation technique could be an addition in the multidisciplinary team of expertise necessary for heritage conservation. More research will need to be carried out to develop comprehensive guidelines and specifications for digital documentation.

Many shophouses are privately owned and thus access for scanning is a challenge. Privacy and confidentiality of scanned information, videos and photographs are of great concern.

[2] These are approximate prices from 2021

Owners may not be willing to allow such information be shared and made available through public platform.

5.2 Opportunities

The use of scanning techniques and photogrammetry to produce 3D models for recording features in cultural heritage such as shophouse is advantageous compared to photographs, as relatively accurate dimensions and geometry of features can be captured. This is particularly true for non-linear, carved, mouldings and curved decorative features. The digital models may be used to re-create the elements and features in case a replacement is required.

The model and photographic records may be useful for setting up of 3D repository of architectural features and elements of shophouses. Detailed ornaments of relief and murals may be modelled and used in conservation documents instead of purely photographs. This provides opportunities of using the elements for components library (Cui, et al., 2015) and database which could possibly correlate and link different houses in Singapore and even other Asian cities.

Matterport, with its online viewing platform, makes sharing of information seamless for various stakeholders. This is a simpler and less complex sharing of information compared to HBIM (Heritage Building Information Management) platform.

The various architectural elements of the internal of the shophouse may be segmented and developed into database for restoration guidelines, BIM and database query application. With additional parametric and standardized information system, the database can be made searchable for users.

6. CONCLUSION

This study evaluated four methods, Matterport Pro2 3D Camera; GeoSLAM ZEB Horizon Handheld LiDAR; Leica RTC360 3D Terrestrial Laser Scanner and Flyability Elios2 Indoor Drone, for 3D documentation of a typical shophouse. Sample features and parameters were selected for comparisons in terms of output quality, operations, and cost.

From the evaluation, Matterport (photogrammetry) is suitable and simplest for producing photorealistic images and clear scans of the shophouse. However, the geometry from the 3D model is compromised with this method. ZEB Horizon (mobile LiDAR) produces relatively accurate model for producing dimensioned drawings of overall structure but is extremely poor for curved, thin and small features. RTC360 (static LiDAR) produces the most accurate model over a wide range of feature sizes. The quality of the optical output is relative good. However, the time taken for data capturing is approximately 12 times longer than the faster methods. Another study (Rodriguez-Gunzalvez, et al., 2017) reported 127 hours and point cloud density of 15mm (at average scanning of 20m) on static LiDAR compared to 1 hour and point cloud density of 60mm (average scanning distance of 25m) on mobile LiDAR. Elios2 (photogrammetry) method provides good visual output for inspection, and the quality and dimension of the 3D models are better than Geoslam.

In general, mobile LiDAR data capturing technique provides more flexibility, better operational efficiency, smaller data volume and processing time compared to static LiDAR technique.

From the video, photographs and 3D model captured and produced, the condition of the conserved shophouse can be established for initial assessment to explore the conservation strategies. The different geometries and scale in the scanning of the shophouse highlight the capabilities of different methods.

As such, a combination of methods may be required for comprehensive recording of all the features of similar shophouse. The intricate and complex architectural features may be better captured with geometry using digital documentation. A complete 3D recording also improves flexibility for data-sharing with various stakeholders and ensures all important features are captured as compared to photographic recording which oftentimes, display only sample photographs of the features.

More evaluations may be carried out using other photogrammetry methods such as high-end camera for lower costs alternative to document shophouse. High end DSLR camera is a possible option and may be explored for documentation of shophouse. Hybrid method with a combination of data from 2 data capture methods are possible to improve the output. However, due to time limitation, this was not carried out within this project.

With 3D digital documentation of shophouse, it is possible to capture the house before conservation as well as to improve its management. As observed in the 3D model samples, geometrically complex features may be accurately captured to generate "reality-based and reconstructive model" (Russo & Guidi, 2011). These can also be used for setting up a digital database / vaults for various architectural features for research and sharing among cities with history of shophouse architecture. Temporal, historical, and spatial research may be carried out using these 3D models. Parametric components of shophouses may be developed (Chevrier, et al., 2010). In order to enhance the database, 3D information has to be complemented with other attribute parameters and made searchable.

The implementation of 3D digital documentation for heritage recording has many advantages and potentials. However, expertise familiar with both digital documentation and heritage conservation is still lacking. The variety and geometrical range of features pose a problem to the selection of data capturing technique and data processing. There are still barriers to the implementation and adoption of 3D digital documentation techniques as the de facto method. In similar shophouse with wide range of feature types and geometries, it may be necessary to set different requirements in terms of Levels of Detail (LOD) to enable comprehensive documentation.

More study in this field requires a multi-disciplinary approach with the use of technology for the digitization, representation, documentation, conservation, and communication of cultural heritage. A searchable central depository of historical architectural elements of shophouses is useful for improving effort and information for their conservation. This is a challenging task which requires more resource.

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