Utilisation of a New Terrestrial Scanner for Reconstruction of As-built Models: A Comparative Study

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ABSTRACT

Recent studies show a great potential of improving construction productivity through using real-time applications to measure change orders and other objects to create as-built. As an enhancement to this promising concept, this paper presents the process of implementation of an efficient framework for as-built Building Information Modelling (BIM) using a new Scan Station that enables contractors to acquire accurate data and create and update the as-built models. A novel framework designed and assisted in the conversion of the raw 3D point cloud data from a laser scanner positioned at multiple locations of a facility into a compact and semantically rich model. The result of the study was compared with two other as-built models using mobile and terrestrial lidar scanners to understand the capability of each for building information modelling. It was found that the framework using the new Scan Station has a great potential to collect accurate data that can be transferred to BIM for creating as-built models. The results show that the accuracy of fine objects' dimensions varies from -2% to +2%. The comparison of the test results with our previous experiments using different scanners shows that every scanner has its own advantage for each job in construction.

Keywords –

Implementation, lidar, Construction technology, Building Information Modelling; laser scanner.

1 Introduction

Laser scanners increase the accuracy and speed of 3-dimensional (3D) data acquisition for the digital as-built generation process. There is a new trend in the use of laser scanners to acquire reliable and accurate data for building information modelling [1-4]. That is why many policy makers and organisations encourage the construction industry and the associated organisations to take up scanners and create information modelling. For example, the United States General Service Administration's Office of the Chief Architect (OCA) has commanded that every federal facility projects should be documented in 3D coordinates using the laser scanning technology for acquiring building spatial data [5]. However, the current practices' accuracy still needs to be improved for as-built documentation purposes [6].

Scanners have many applications in construction. One of the most important applications are acquiring data for creating as-built modelling in construction, because owners need as-built models with more accurate data. The available technologies and method for creating as-built are: manual survey (traditional), non-range based (visual-based) technology and range-based technology. The capability of lidar as a tool to collect a large amount of accurate 3D data has been investigated and applied using the existing technologies. While many studies attempted to provide new solutions to collect and record the completed construction objects for as-built purposes, the effort to automate the process of an as-built creation on time is still in the early stage and very challenging [7, 8]. Therefore, there is much work needed to improve the accuracy of the current practices considering cost and time in construction [6]. Recently, improving the level of details in as-built is recognised as an open question [7, 9]. On the other hand, integration of the detected fine objects and the data into BIM as a new paradigm of a knowledge sharing system is still challenging, and the use of appropriate hardware, structure, and ad-hoc algorithm still needs to be enhanced [7, 10].

This paper aims to examine how different scanners can be used for acquiring 3D lidar point cloud data in order to incorporate into BIM. The main objectives of this paper are: 1) to implement a new laser scanner to create as-built information modelling; 2) to compare the results of the experiments of both mobile and terrestrial scanners across different technological attributes; 3) to identify challenges and opportunities for selecting and using a scanner for as-built work in construction. The originality of this paper lies in implementing advanced technologies to identify the differences and attain the feasibility of real-time indoor data acquisition for creating as-built BIM.

The paper firstly reviews existing techniques for creating as-built which are mostly manual processes; and identifies technology gaps and barriers to the automation process. Secondly, a novel framework is implemented and the results are verified using independent datasets of a sample educational building at the University of New South Wales, Sydney, Australia. Thereafter, the result of the paper is compared with three other field operations, and the results will be discussed focusing on advantages and challenges of each method. Finally, investigation of other sample buildings, and new applications of these scanners in 'shop drawing' creating will be suggested as future work.

2 Overview of As-built Creating Methods

The process of as-built information modelling using new technologies can be divided into two main phases: data acquisition and building information modelling.

2.1 Data Acquisition Methods

Several techniques can be used for data acquisition in order to create as-built in construction. However, there are limited techniques to acquire data with possibility for creating digital modelling.

Traditional as-built practices are mainly based on graphical standards for 2D drawings [11]. To develop such illustrations in two or three dimensions, traditional measuring equipment is used. The accuracy of these traditional as-built methods is within the required tolerance [12]. However, this traditional method of data acquisition produces a massive number of drawings so that their management and usage are time consuming [13]. For example, Wang and Love [14] explained that traditional site layout method is labour intensive and required many times of re-measuring. Historically, sketch and photos are used to supplement the traditional method to assist CAD operators to enhance the information and accuracy of traditional as-built planning without any ground control [15]. Recently, researchers try to use photogrammetry techniques to produce digital and parametric data for as-built information modelling. Photogrammetry refers to geometric information derived from photographs [16, 17]. However, this method has limitations [16, 18].

Table 1 shows some of limitations of photogrammetry methods for collecting data for as-built creation. For example, extracting object points from a wide angle shots nearby an object is difficult [16]. This approach is not able to produce the required information about the topography of irregular shapes in detail, and cannot provide the details of curves and irregular shapes, whereas lidar scanners can capture such details easily. Photogrammetry usually cannot be used independently in creating as-built, and it is not an ideal solution for as-built [19]. Recent studies attempt to integrate digital photogrammetry with lidar scanners [15, 20].

Table 1 Constraints of using photogrammetry for creating as-built

Existing studies	Constraints and examples
Photography using single camera: Case of Bridge [18]	Occlusion (-): temporary supporting structures make some edges invisible in one photo of the objects.
Photography using single and stereo set up camera: case of building façade [21]	Accessibility (-): the camera is not allowed to be placed everywhere in the site, because of safety hazards or obstacles.
Photography using single camera: case of building (Ceiling, Door, Perimeter, Window) [16]	Difficulty of stitching repetitious facades with limited views (-): this reduces accuracy, even with the additional markers placed on the columns.
Photography using single and stereo set up camera: case of building façade [21]	Accessibility (+): 54 windows were accessible by the image-based survey, which were not accessible through the manual survey.
Photography using single and stereo set up camera: case of building façade [21]	Indoor vs. outdoor (-): shooting locations in indoor and outdoor environments require tailor-made measurement methods for acquiring images.

Note: '-' refers to disadvantage and '+' refers to advantages of the method.

Lidar is a laser imaging technology that is increasingly employed for capturing scenes with millimetre to centimetre accuracy. It provides fast, accurate, comprehensive and detailed 3D data about the scanned scenes at the rate of hundreds of thousands of point measurements per second. Laser scanners collect data in the form of point clouds which are shapes and dimensions of objects in real space converted and represented as a collection of points in a 3D digital space.

Recently, lidar is widely used for construction purposes [22, 23]. Particularly, several studies attempted to use lidar for as-built creation [24, 25]. However, there are two main problems in this stream. First, geometric information such as lines and surfaces cannot be easily extracted from millions of points data of objects in an automatic manner [26], hence are recommended as future research [26, 27]. Second, a limited number of scanners such as terrestrial scanners are suitable for BIM [25], and the state-of-the-art technologies are not investigated fully.

Table 2 compares two methods for acquiring data for building information modelling. Corresponding to the challenging problem of reliable data collection of constructed objects in a timely manner, scanners can be proper devices of data collection for as-built creation in construction. The comparison suggests that the current methods cannot be the most accurate and/or fastest solution to be employed as the best solution for contractors. In order to find other solutions, this paper attempt to experiment a new laser scanner.

Table 2 Comparing two as-built methods

Item	Traditional	Photogrammetry
Hardware	Tools	Portable tool
Portability	Hand held	Hand held [17]
Skill	Low	Low
Equip. cost	Hundreds	Hundreds [17]
Resolution	Low	Low [16]
Accuracy	Centimetre	Centimetre [16]
Tolerance	Accepted as required tolerance [12]	Accurate [17]
Time	Time consuming [13]	Quick
Workability	Labour intensive and required re-measuring [14]	Extracting object points sometimes are difficult [16]
Size and complexity of the work	Highly influence the work	Highly influence the work
3D Modelling	Manual, 2D drawings [11]	Post-process [16], and is not independent method to create models [19]
Retrieval	Manual	Manual
Spatial data speed	Not real time	Not real time retrieval [18]
Range	-	Medium [18]
Operation time	Sensitive to light [18]	Sensitive to light [18]
Whether condition	Influence the work	Influence the work

2.2 Building Information Modelling

BIM is a collection of data which digitally represent the relevant characteristics of a building [28]. It is created through a process of modelling which includes practices such as distribution and storage of these data-sets. BIM is a rich data platform, but it is not practical if it only represents the design, and not the building as it is built.

As-built BIM includes all the changes made on the building during the construction phase; it can be an up-to-date representation model of the building. The widespread use of as-built BIM is prevented by the lack of a time-efficient and accurate method of easily creating BIMs [8]. The capabilities of BIM as representation models and its requirements for as-built BIMs are well investigated [29-32]. However, Huber et al. [8] claimed that the topic of representing as-built BIM is in its early stage. Furthermore, current procedures rely on manual processes which are labour-intensive, time consuming and susceptible to errors [7]. According to Tang, Huber [7] existing work focuses on modelling the simplest objects of a building rather than modelling complex objects such as doors and windows. In addition, they showed that there are significant disconnections between surface-based modelling and volumetric modelling representations [7].

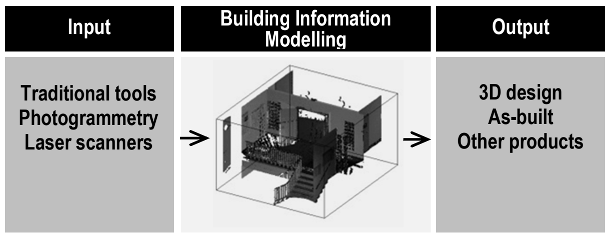


Figure 1. Acquiring data and information modelling are major phases resulting in as-built modelling.

Figure 1 shows that the literature is divided into three main categories: input, modelling and output. The literature shows that study to examine new technology applications to acquire input data for creating as-built BIM is scarce. However, much study focused on modelling and the output of modelling. This paper implements a novel terrestrial lidar to create as-built BIM in construction. The review reveals three significant challenges for creating as-built BIM. First, modelling fine and complex objects of buildings have received little attention [7, 8]. Second, a procedural approach toward automatic as-built creation of the entire building is still unachievable [29]. In this paper, the fine objects of a relatively complex building are selected to carefully experimented and modelled.

3 Methodology

This paper attempts to develop a model to create more accurate as-built with low skill labours in a short time. Based on the literature and previous work, the overall process for as-built creation is proposed consisting of scanning, processing, and creation. The procedure consists of eight stages. In the data collection step, an educational building at the Kensington Campus of the University of New South Wales has been scanned using a Leica ScanStation C5 scanner. Next, the data is registered and obvious noises were removed. Main elements including openings, walls, floors and ceilings were segmented in the next step. Then, the extracted elements were combined as the identified as-built elements. Field work was conducted to assess and verify the level of accuracy obtained using the dense lidar points.

3.1 Details of Study Extent

Figure 2 show the sample building and the selected partition on the 4th floor. The sample includes windows, doors and stairs and it is complex enough to explore the accuracy of the work for different architectural elements, i.e. modelling such fine objects and details are still challenging.

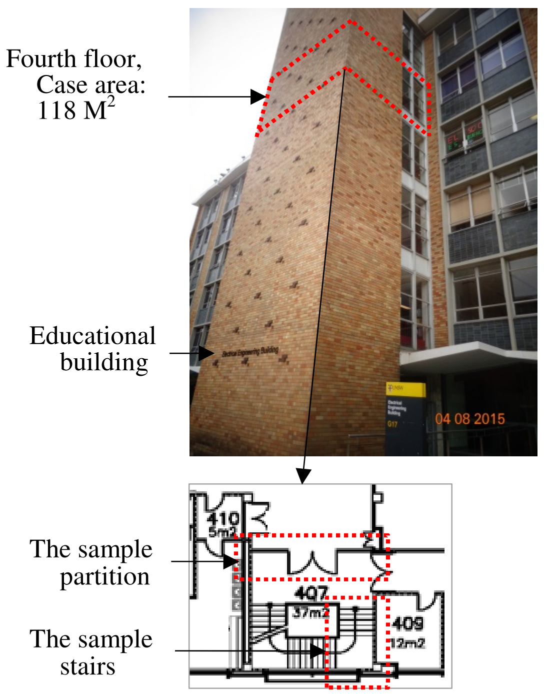


Figure 2. The sample location and layout plan for experiment.

The experiment includes collecting data set by using a state-of-the-art scan-station called Leica C50 at two locations from less than 3 meters distance from the objects at two locations. The results of the experiment is discussed in this paper and compared with the previous two experiments. The maximum distance measurement and the maximum range are 35 to 300 meters, respectively.

The results of analysing the data set was cross-validated by the results of the previous findings by using a multi-station called Leica Nova MS50 in a similar position as the current experiment in this paper. The maximum distance measurement and the maximum range are 50 and 1000 meters, respectively, for this multi-station. For more information, see Sepasgozar, Lim [4].

4 Results and Discussion

4.1 Scan Station Set up and Triangulation

Figure 3 shows the stations of the terrestrial scanner adjustments. The Leica ScanStation C5 was adjusted at two locations as shown in the layout plan. The process of data collection with high resolution mode took about 40 minutes from two locations.

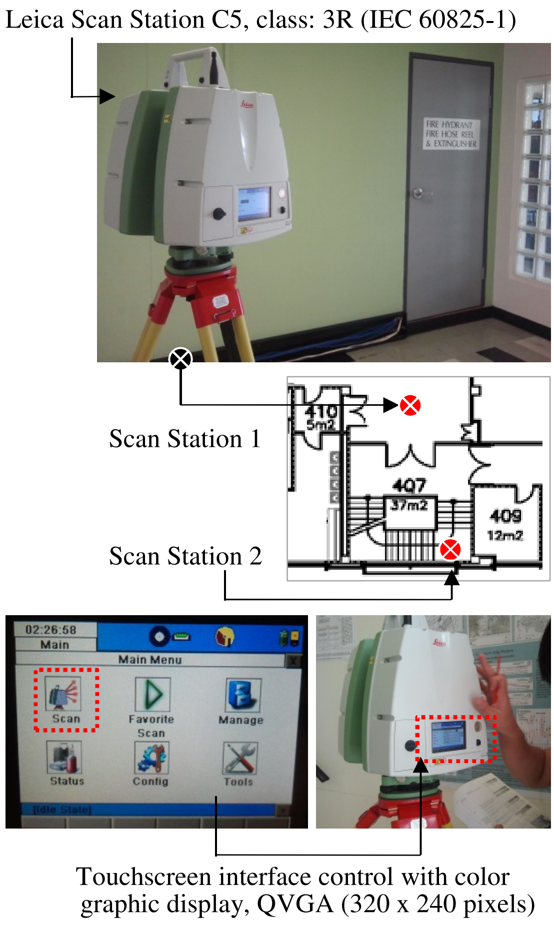
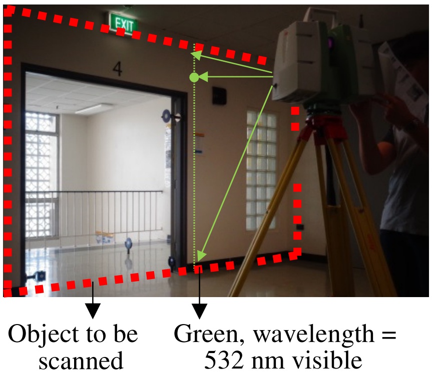
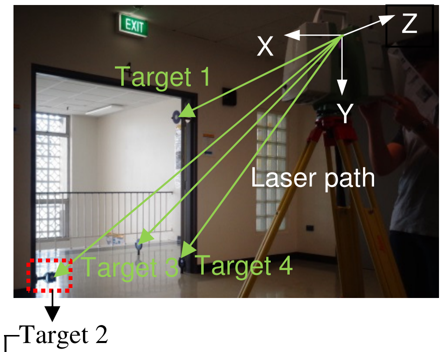


Figure 3. Adjustment and implementation of terrestrial scanner.

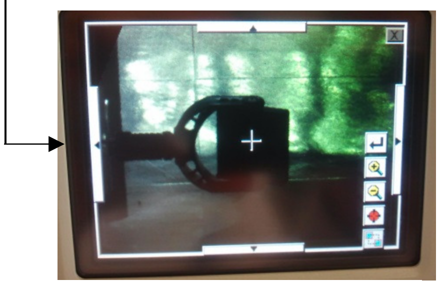
Figure 4 shows that the scanner scans four targets. Since, scanners cannot accurately point at a single point; the surface targets are usually scanned. Then, the surface will be scanned and the best fit of the target will be calculated.



a) Field-of-View: Vertical 270° (maximum), Horizontal 360° (maximum)



b) Axes of the coordinate system in relation to the object



c) Display of the Target 2 with the white cross close to the centre.

Figure 4. Scanning four targets

There are different target types: plane, sphere and cylinder. In this experiment, we used plane targets as shown in Figure 4. The targets have the advantages to be turned when the scanner adjusted in the opposite side of the partition. The common points from the two sides can be features of the object (e.g. the wall, window or door). However, the special targets were used to increase the accuracy of transformation process.

4.2 Data Process

In order to compare the result of different datasets from this study and our previous experiments [3, 4], the same segment including the partition wall. This data collected by terrestrial lidar (C50) contains less noise points compared to the mobile lidar.

Pre-processing of the datasets requires firstly, conversion of the collected files to '.pts' and '.rcs' files for visualization purposes and secondly, detection and reduction of noise (i.e. unwanted objects such as furniture). A sample of data with the noise is shown in Figure 5. In this stage, the data was registered. The datasets then were segmented to wall, floor and ceiling. Thereafter, the processed terrestrial lidar datasets were imported and processed into Autodesk Revit and converted within the program into a compatible format. The segmented components: wall (including windows and an opening) is modelled as shown in Figure 5. The 3D model for the whole sample partition is shown in Figure 6.

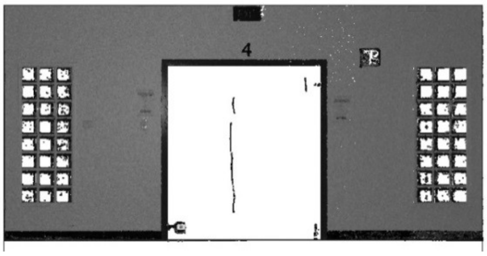


Figure 5. The data from the partition wall with noise.

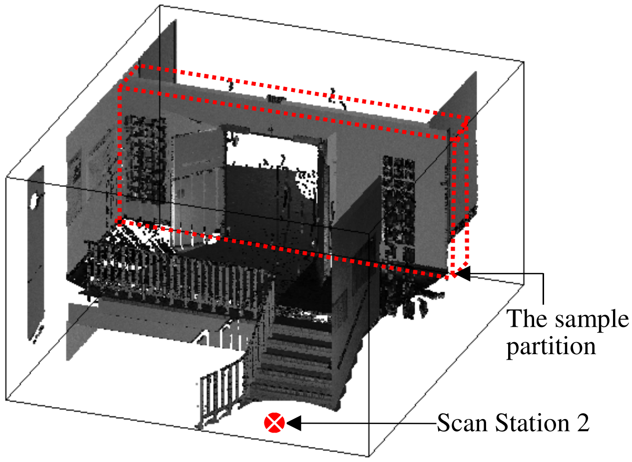
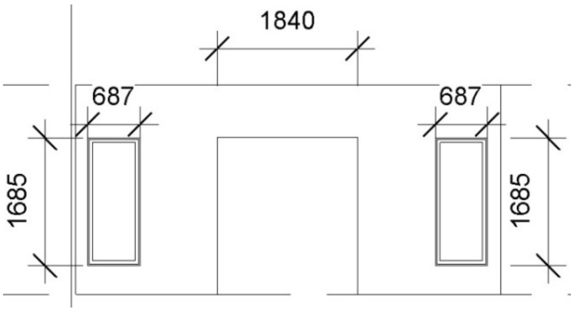


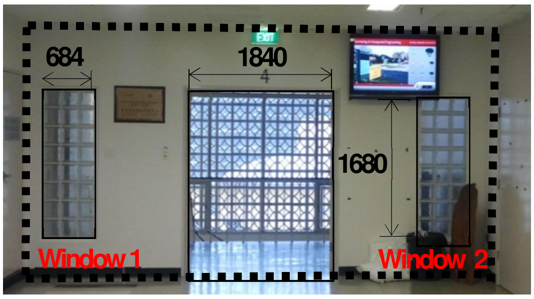
Figure 6. The 3D point clouds of the sample

5 Accuracy Assessment and Validation

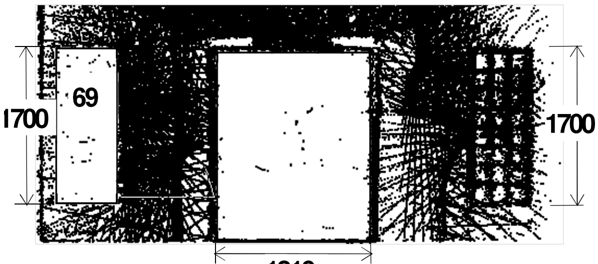
The 3D model developed using the 2D drawings were used as the ground truth for the accuracy assessment analysis. Manual survey measurements were carried out to collect the manual data directly, because it is possible that the original 2D drawings and the existing as-built are not accurate. These measurements and updating existing 2D drawings and the model generated from the manual measurements and photos are worthy to provide evidences for project control.



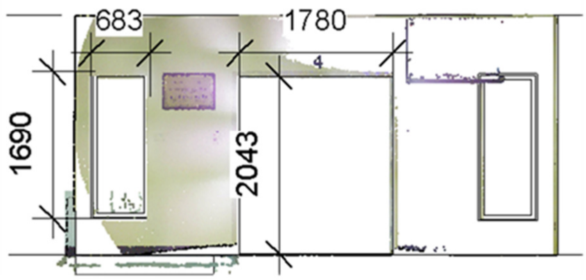
a) Segment of the partition using C50 scanner



b) Traditional measurements of objects of the sample partition in the front view.



c) Segment of the partition using mobile lidar



d) Segment of the partition using Nova L50 scanner

Figure 7. As-built information modelling for the sample partition using different methods and scanners.

Figure 7(b) shows the manual measurements. Figure 7 (c and d) presents other 3D models that created previously. These models are used for cross-validation of the data and calculate the differences of the dimensions.

Stationing and scanning for the partitions and stairs are almost similar to the previous terrestrial scanner experiment about 40 minutes. This time is dependent to the scan mode (high resolution or regular) and the skill of operators for adjustments and operation. This shows that the mobile hand-held scanner is very fast, and does not need a skilled technician for adjusting and using the equipment.

Figure 8 and Figure 9 shows the measurement results for four different experiments: traditional (manual surveying measurement, mobile and terrestrial lidar with Nova 50, and the current experiment with ScanStation C5. The performance of terrestrial lidar is better than mobile lidar in terms of small objects such as windows measurements.

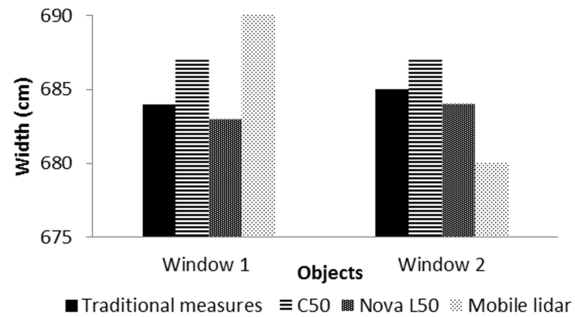


Figure 8. The results of four experiments for windows' width.

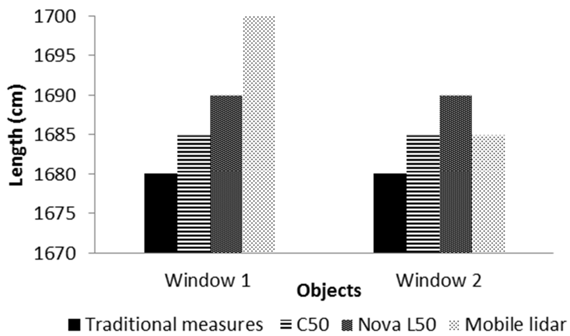


Figure 9. The results of four experiments for windows' length.

Further analysis applied on the measurements of doors and windows, and the residuals of the surveying measurements and the three other each experiments were calculated. The surveying measurements are the manual measures that used for accuracy assessment and as comparative measures. Standard Deviation for these three residuals for mobile lidar, Nova L50 and C5 are 19.3, 26.3 and 1.9 mm respectively. The findings show that C5 has a big difference than others for scanning openings, and is more accurate than others in this sample.

The accuracy of the result of implementations of the frameworks using terrestrial lidar C50 comparing traditional measures varies from -2% to +2% for openings, while this accuracy for the other two experiments are varying between -3% to +3% and from 1 mm to 12 mm. The results from terrestrial lidar scanners are more accurate and closer to the manual survey measurements than mobile lidar scanner for small openings.

The findings show that ScanStation C5 gives more accurate results for openings than other experienced scanners. The cost of implementing this scanner ($70,000) is three times more than mobile lidar ($25,000) and much more expensive than manual surveying measurement. In terms of performance and operation, ScanStation C5 needs several targets when we need to scan a large area. This increases the difficulty of the operation, because the operator should carefully use targets and scan them. All targets should have the unique numbers, and this should be considered when the scanner moves to another point for the same target. Mobile scanners do not need this process in operation.

All in all, the results show that the terrestrial lidar is more accurate than the mobile lidar in most of the cases, and from visual inspection less noise points can been seen in the terrestrial lidar data than the mobile lidar data. Both terrestrial and mobile lidars are accurate enough for construction purposes. However, for scanning small objects where high accuracy is needed, we recommend to use terrestrial scanners. For larger objects, where the contractor needs quick results, mobile scanners are more suitable with low cost in operation and ownership.

6 Concluding Remarks

This study aimed to implement a novel framework for accurate as-built modelling using 3D point cloud data captured by new scanners. A new ScanStation lidar scanner is used in order to examine the developed framework for creating as-built modelling and also to experiment the acquisition flow of the required information of the ScanStation from a raw lidar point cloud. In this study, we implemented the process to obtain dimensions of fine objects of a complex building. The dimensions are cross-validated with three other experiments by using manual survey measurements, mobile and Nova L50 terrestrial lidar, and the results are more accurate than the current as-built which were created by a construction team, and the accuracy is higher than the previous work at some areas such as openings and stairs.

This study shows some significant potential benefits that can be improved by implementing the framework in terms of easy operation and the accuracy of creating as-built BIM.

As for future work, we suggest to pick many other objects in the building and statistically examine the differences of each scanner for different dimensions (e.g. vertical vs horizontal, fine vs large objects, indoor vs outdoor objects). In addition, other types of construction sites such as tunnels, railways and mining objects should be examined. The ability of the framework to create shop drawings and real-data acquisition should be examined, as we see the potential of the framework and utilised tools in this paper.

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