

Implementation of As-Built Information Modelling Using Mobile and Terrestrial Lidar Systems

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Abstract -

Recently it is observed that there is an increasing trend of using lidar point clouds in construction, since lidar is able to provide highly accurate 3-dimensional representations of objects. The flip side of a lidar point cloud is its massive size and therefore prolonged time for data processing. Our research aims to develop an efficient framework for as-built modelling in terms of time, cost and performance. For this, we collected lidar point clouds using two different data collection methods (i.e. mobile and terrestrial lidar systems with a few centimetre level accuracy) and constructed solid 3-dimensional models of a building. The procedures of creating as-built models from both data acquisition methods are compared to understand the capability of each for automatic building information modelling. In order to create as-built models, a framework consisting of eight key stages from data capturing to constructing the building information model is developed. It was found that the framework using mobile lidar enables contractors to create as-built models for complex objects in a timely manner, whereas the framework using terrestrial lidar provides us with more accurate as-built information models. The implementation results of the two frameworks using mobile and terrestrial lidar systems vary between 5-30 mm and 1-45 mm, respectively. It is anticipated that the proposed study becomes a step forward to full automation of lidar-based building information modelling.

Keywords -
As-built; Scanner; Mobile lidar; Terrestrial; BIM, Construction

1 Introduction

An emerging technology such as lidar provides an opportunity to move forward to a cost-efficient way of as-built creation. Construction engineers are willing to

adopt such a technology in order to increase the accuracy and speed of the digital as-built generation process. The United States General Service Administration's Office of the Chief Architect (OCA) has commanded that every federal facility projects should be documented in 3-dimensional (3D) coordinates using the laser scanning technology for acquiring building spatial data [1]. However, the current practices' accuracy still needs to be improved for as-built documentation purposes [2].

After conversion to a suitable format, the data captured using lidar scanners can be stored in building information modelling (BIM) as 3D objects with the attached attribute information. However, collecting and incorporating reliable as-built data for BIM is still challenging, when considered accuracy, time and cost constraints [3]. According to Giel and Issa [2], there is a great disconnection between the data derived from remote sensing and the creation of as-built using BIM.

Details and specifications of many construction objects that are left behind walls, covered by another item or buried for another scheduling, could not be detected in each stage. The main reason for this problem is that surveying-quality scanners are relatively expensive and difficult to adjust or relocate the equipment through the construction site even by highly skilled technicians. Therefore a tool capable of detecting objects and collecting accurate coordinates of the objects in a timely manner would have a significant value for contractors and contribute to the information flow and modelling in construction.

The importance of as-built for the owners and project managers has been well documented [4]. Several technologies are available for creating as-built models. Recently, lidar is introduced to the construction industry for different purposes [5-7]. The capability of lidar as a tool to collect a large amount of accurate 3D data is investigated and applied using the existing technologies. While many studies were 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 [3, 8]. For example, Dore and Murphy [9] presented a semi-automatic approach for generating BIM façade models for existing buildings, and concluded that future work requires procedural development for generating entire building models, rather than parametric library objects such as column and pediments. In addition, they suggested that future work should be more comprehensive to serve end-users [9]. Therefore there is much work needed to improve the accuracy of the current practices considering cost and time in construction [2]. Recently, improving the level of details in as-built is recognised as an open question [3, 10]. 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 [3, 11].

This on-going study aims to provide a procedural framework to rapidly incorporate 3D lidar point cloud data captured by a mobile lidar into BIM. The main objective of this paper is to develop a rapid as-built model (*rABM*) using the state-of-the-art mobile and terrestrial lidar equipment.

The originality of this paper lies in implementing a framework to use a novel hand-held mobile lidar for real-time indoor data acquisition for creating as-built BIM. The presented framework enables contractors to create as-built BIM in a cost-efficient and timely manner. In addition, comparing two new technologies reveals a possibility for current construction needs for creating as-built for complex buildings in limited and small areas. On the other hand, the comparison assists vendors and innovators to enhance the feature and capability of next generation of scanners to cover limitation of as-built creation modelling barriers.

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, the framework is implemented and the results are verified using extra independent data sets of a sample educational building at the University of New South Wales, Sydney, Australia. Thereafter, the results of a comparison matrix of two filed operations and results will be discussed. Finally, investigating other sample buildings 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.

2.1.1 Traditional Practice

Traditional as-built practices are mainly based on graphical standards for 2D drawings [12]. 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 [13]. However, this traditional method of data acquisition produces a mass of drawings so that their management and usage are time consuming [14]. For example, Wang and Love [15] explained that traditional site layout method is labour intensive and required many times re-measuring.

2.1.2 Photogrammetry

Historically, sketch and photos are used to supplement traditional method to assist CAD operators to enhance the information and accuracy of traditional as-built planning without any ground control [16]. 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 [17, 18]. However, this method has limitations [17, 19]. For example, extracting object points from a wide angle shots nearby an object is difficult [17]. 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 [20]. Recent studies attempt to integrate digital photogrammetry with lidar scanners [16, 21].

2.1.3 Lidar Solutions

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 [5, 22]. Particularly, several studies attempt to use lidar for as-built creation [6, 23]. 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 [24], and are recommended as future research [24, 25]. Second, a limited number of scanners such as terrestrial scanners are suitable for BIM [6], and the state-of-the-art of technologies are not investigated fully.

2.1.4 Comparing Possible Solutions

A summary of comparison of as-built methods is provided in Table 1. 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 laser scanners are an accurate and fast solution that will be employed in this paper. It should be noted that the previous scanners used for as-built creation purpose were bulky as it is stated in Table 1. In order to solve these problems, we will use a novel mobile equipment to acquire data.

Table 1. Comparing three as-built methods

Item	Traditional	Photogrammetry	Lidar
Hardware	Tools	Portable tool	Scanners
Portability	Hand held	Hand held [18]	Bulky
Skill	Low	Low	Medium-high
Equip. cost	Hundreds	Hundreds [18]	Thousands
Resolution	Low	Low [17]	High
Accuracy	Centimetre	Centimetre [17]	Millimetre
3D Modelling	Manual	Post-process [17]	Automatic meshing [17]
Retrieval	Manual	Manual	Automatic
Accuracy	Accurate	Accurate [18]	Most accurate
Spatial data speed	Not real time	Not real time retrieval [19]	Real time retrieval
Range	-	Medium [19]	Long [19]
Operation time	Sensitive to light [19]	Sensitive to light [19]	Anytime [19]

2.2 Building Information Modelling

BIM is a collection of data which digitally represent the relevant characteristics of a building [26]. It is created through a process of modelling which includes practices such as distribution and storage of these datasets. 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 [2, 9, 27, 28]. 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 [3]. According to Tang et al [3] 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[3].

In summary, the review reveals three significant challenges for creating as-built BIM. First, previous work mainly used terrestrial scanners and stationary lidar equipment [2, 3, 8, 9]. Second, modelling fine and complex objects of buildings have received little attention [3, 8]. Third, a procedural approach toward automatic as-built creation of the entire building is still unachievable [9].

3 Methodology

3.1 Study Framework

Using new technologies, innovative algorithms assist us to create semi-automated and rapid as-built modelling (*rABM*) for creating and updating as-built building information models in each stage of the project. With this intention, this paper attempts to take the first step forward to develop the 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. In addition, the algorithm and feature of the new hand-held rapid laser which is used in this paper dictated us to follow a new procedure to create *rABM*. The result will be verified by a data set acquired from a terrestrial lidar.

The *rABM* consists of eight stages as shown in Figure 1. In the data collection step, one building at the Kensington Campus of the University of New South Wales has been scanned using the mobile mounted range-sensing system, and a terrestrial 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.

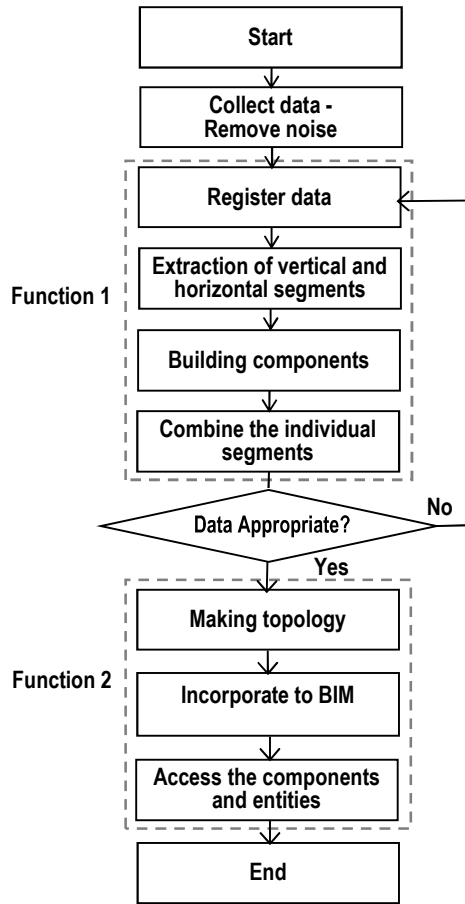


Figure 1. The flow diagram of the algorithm of the solid as-built modeling from lidar data

3.2 Device and Algorithm of Data Acquisition

A novel handheld mobile lidar is used to implement the framework. The results are validated using the state-of-the-art terrestrial scanner.

3.2.1 Mobile Lidar

The first set of data was captured utilising a handheld mobile mapping device including a lightweight lidar scanner. The utilised device is a 3D sensor system that consists of a rotating and trawling 2D lidar and a MicroStrain miniature internal measurement unit (IMU) mounted on a spring mechanism. This equipment, namely Zeb1 designed on the basis of a 3D simultaneous location and mapping (SLAM) solution [29], while other mobile mapping methods are based on GNSS that cannot be used for indoor mapping purposes. The laser of the scanner is a Hokuyo UTM with 270-degree field of view, 30 meter maximum detectable range. The total weight of the system is about 510 g. The handheld device has a small battery that is sufficient for the whole operation and a data acquisition laptop which was carried in a backpack by the operator.

We utilised the proposed technology because, in contrast to stationary terrestrial lidar, the hand-held mobile lidar does not need a tripod or a vehicle and skilled operations. The 3D point was generated when the scanner was waved by hand and moved twice around within about 100 mm distance and oriented in the same direction back way through the corridor of the building. The device was transported through a loop in the corridor of the building on the 3rd and 4th floors.

Indoor points of the study extent were scanned using an algorithm of acquiring points that takes advantage of recording points against a trajectory route and other points. This algorithm is capable of measuring thickness of the interior partition walls that will be discussed in the results section.

3.2.2 Terrestrial Lidar

The second data set was collected using a state-of-the-art multi-station called Leica Nova MS50 at two locations from less than 3 meters distance from the objects. The maximum distance measurement and the maximum range are 50 and 1000 meters, respectively, for this multi-station.

3.3 Details of Study Extent

The study extent and the sample partition on the 4th floor are shown in Figure 2 (a). A part of building with windows, doors and stairs were selected as 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. The general attributes of the case study are represented in Table 2. For consistency in understanding the analysis, pseudonyms are used for the parts such as W₄ to refer to the west wing and C₄ to refer to the middle corridor of the 4th floor which is being studied.

Table 2. The profile of the object/case

Attributes	The building case	The case C ₄
Location	Randwick, Sydney	The middle corridor
Use	Higher education	Crossing corridors
Type	In use	In use and decorated
Scope	4-Storey building	The partition wall
Materials	Mix	Glass, steel and concrete
Point	27,000,000	7,257,030

4 Results and Discussion

The results of implementation of the framework are separately discussed in this section.

4.1 Mobile lidar

Scanning the indoor environment of two levels of the building using the handheld rapid-laser mapping system took about 20 minutes. The point cloud segment of 4th floor is overlaid on the layout plan of the same place (see Figure 2a) and the open-loop trajectories of the scanner are shown in Figure 2 (b). The sample is shown in A–A view (Figure 2 a) from the north-south corridor of level 4 called C₄. Using a segmentation technique, the 3D point cloud of this area was analysed to obtain the required dimensions for parametric modelling. In the current practice, registration is a semi-automated process. Data processing is also a semi-automated process that includes manual and automated filtering to remove noises and unwanted data, such as points from moving objects and reflections.

4.2 Terrestrial lidar

The multi-station terrestrial scanner (Figure 3) was set up at two locations as shown in the layout plan Figures 2a and 3. The process of data collection took about 30 minutes from two locations including stationing and scanning.

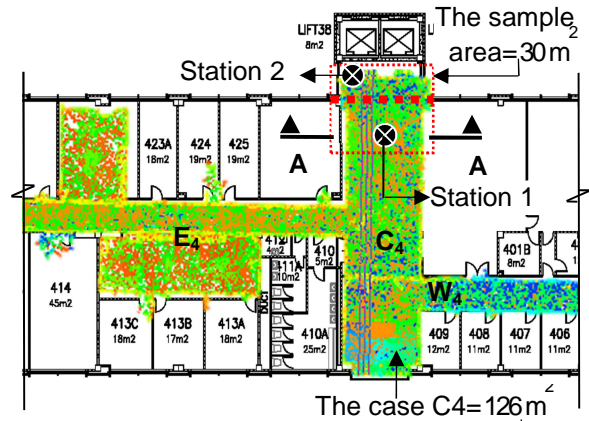
In order to compare the result of two different data sets, the same segment of A–A is selected. This data collected by terrestrial lidar contains less noise points compared to the mobile lidar.

4.3 Modelling Process

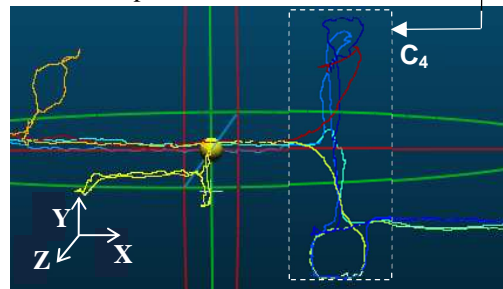
Pre-processing of the data sets requires firstly, conversion of the text files to .ply and .las files for visualisation purposes and secondly, detection and reduction of noise (i.e. unwanted objects such as furniture). The data sets then were segmented to wall, floor and ceiling. Thereafter, both processed mobile and terrestrial lidar data sets were imported and processed into Autodesk Revit and converted within the program into a compatible format. Two segmented components: wall (including windows and an opening) and a section of stairs of the sample C₄ are modelled as shown in Figure 4d. Levels were allocated in components and a model was created.

4.4 Comparison of the Results

Table 3 shows the measurement results from three different methods: traditional, mobile and terrestrial lidar. While the performance of terrestrial lidar is better than mobile lidar in terms of windows measurements, mobile lidar shows better results in measuring the door dimensions.



a) Overlaid Reference of 4th floor and Lidar top view



b) The Trajectory of Sensor - Mobile lidar

Figure 2. The Data and the Case Samples

The results of terrestrial lidar for the sample partition dimensions (Figure 4d) validate the previous results of mobile lidar (Figure 4b). In addition, experiencing both methods for the same object is valuable, because each method can be used for different applications.

Table 3. Comparison of the measurement results.

The object dimensions		Traditional measures	Mobile lidar	Terrestrial lidar
Stair	L ¹	30	27	29
	W ²	16	15	19
Door	L	2055	2030	2043
	W	1840	1810	1780
Window 1	L	1680	1700	1690
	W	684	690	683
Window 2	L	1680	1685	1690
	W	685	680	684

¹L refers to length of the object. ²W refers to the width of the object.

Mobile lidar scanning took about 20 minutes for the entire collection at 3rd and 4th floors. However, operation of terrestrial scanning consists of stationing and scanning for only the wall from one side took 20 minutes. Similarly, stationing and scanning for stairs took about 13 minutes. In total, using multi-station terrestrial lidar took about 33 minutes only for the sample partition including the wall and five of stairs behind the wall. This shows that the mobile hand-held

scanner is very fast, and does not need a skilled technician for adjusting and using the equipment.

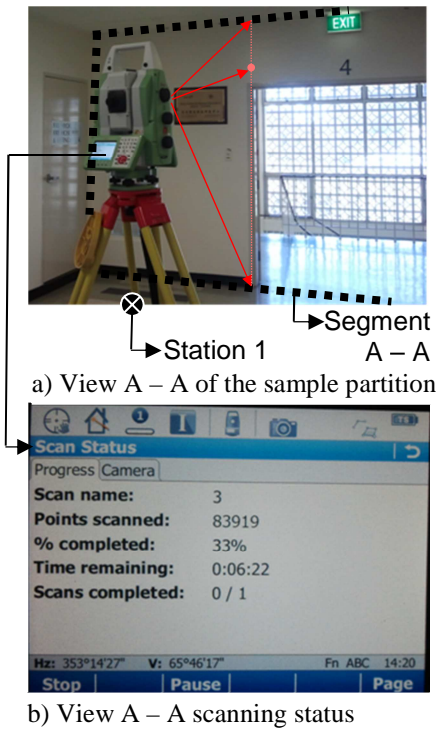


Figure 3. Terrestrial lidar filed work

The accuracy of the result of implementations of the frameworks using mobile and terrestrial lidar equipment comparing traditional measures varies from 5 mm to 30 mm and from 1 mm to 12 mm. The results from terrestrial lidar are more accurate and closer to the field work than mobile lidar for small openings.

Another difference between the mobile and terrestrial lidar is cost. The cost of the mobile lidar is three times cheaper than the multi-station scanner. At the same time, using mobile lidar equipment does not need a skilled operator. However, processing the data collected by the mobile lidar needs a skilled expert compared to the terrestrial lidar which is fully commercialised. A summary of the comparison of two experiments is listed in Table 4.

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 be seen in the terrestrial lidar data than the mobile lidar data. At the same time, the data collection process of the terrestrial lidar is not as fast and easy as the mobile lidar. Both terrestrial and mobile lidars are accurate enough for construction purposes.

The terrestrial lidar equipment is expensive (\$25,000) compared to the mobile lidar (\$60,000). In sum, it is preferred to implement the framework using mobile lidar considering the speed of collection from a

large area of complex buildings by a low skilled operator. Implementing *r*ABM using mobile lidar, the final as-built modelling in BIM created as shown in Figure 5. However, terrestrial lidar is preferred for fine and specific objects in construction such as windows.

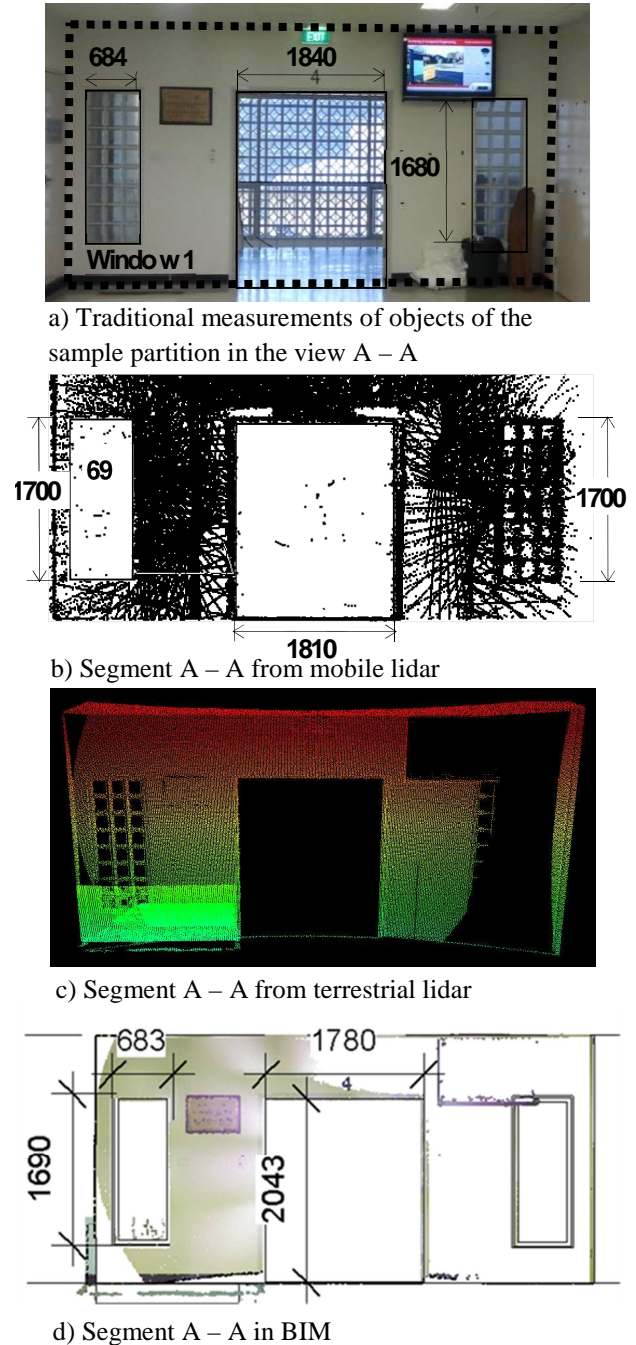


Figure 4. The segments and modeling of the sample partition in the view A – A

In addition, the prior robotics applications are typically concerned with navigations and detection algorithm; whereas the feature of mobile lidar equipment

enables us to use it in small and limited areas of complex buildings where adjusting a terrestrial lidar equipment is not possible.

Table 4. Comparison of the results of Mobile and Terrestrial lidar

Characteristics	Mobile lidar	Terrestrial lidar
Operating	Without Adjustment	With Adjustment
Portability	510 g	7.6 kg
Required skill	Low	High
Estimated cost	About \$25,000	About \$60,000
Resolution	Medium	Very high
Accuracy	Millimetre	Millimetre
Spatial data Retrieval	Semi-automatic	Semi-automatic
Spatial data accuracy	±5 to 30 millimetre	± 3 to 12 millimetre
Spatial data retrieval speed	Real time retrieval	Real time retrieval
Range distance	20	1000
Operation time (for the sample)	10 minutes	30 minutes

5 Concluding Remarks

This study aimed to develop a framework for rapid as-built modelling using 3D point cloud data captured by the state-of-the-art technologies. The 3D lidar scanners are used in order to speed up the acquisition flow of the required information from a raw lidar point cloud. In this study, we implemented the process to obtain dimensions of one complex building. The dimensions are verified using mobile and 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. Therefore, mobile scanners are suitable for collecting indoor data for buildings and can be used in conjunction with terrestrial scanners which are able to collect both outdoor and indoor data.

This study shows some significant potential benefits that can be improved by implementing the framework in terms of time and accuracy of creating as-built BIM. However, there is much work to be done to fully automate the whole process of as-built creation in construction.

As for future work, we suggest to select other types of buildings and construction sites such as tunnels, railways and mining objects. In addition, examining the framework for creating staging as-built during construction is needed as future work.

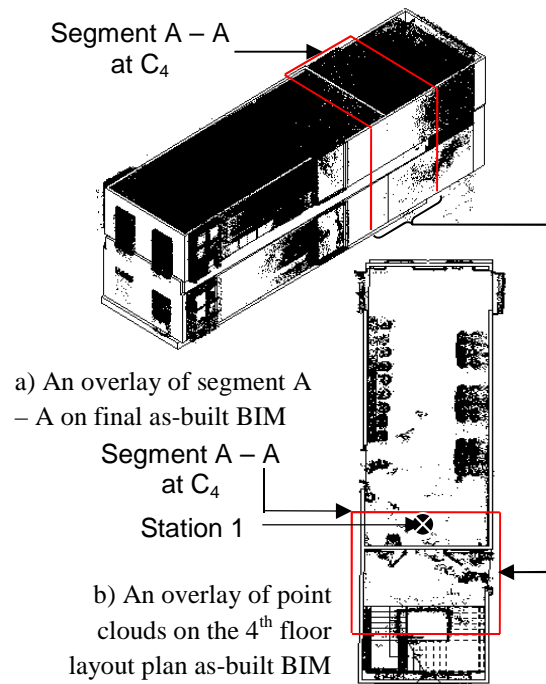


Figure 5. Overlay of mobile lidar and modelling level 2 and 3 of the case in BIM

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