Implementation of Rapid As-built Building Information Modelling Using Mobile Lidar

Samad M.E SEPASGOZAR[1], Samsung LIM[2] and Sara SHIROWZHAN[3]

[1] PhD Candidate in Engineering Construction and Management, School of Civil and Environmental Engineering, University of New South Wales Australia, Sydney 2025, email: samad.sepasgozar@gmail.com

[2] Associate Professor, School of Civil and Environmental Engineering, University of New South Wales Australia, Sydney 2025, email: s.lim@unsw.edu.au

[3] PhD Candidate in Surveying and Geospatial Engineering, School of Civil and Environmental Engineering, University of New South Wales Australia, Sydney 2025, email: s.shirowzhan@unsw.edu.au

ABSTRACT

The need for development of reliable and efficient real-time data acquisition systems has recently attracted a great deal of attention in the construction industry, basically due to the demands for highly frequent updates in most visualization, optimization and coordination-related applications. The predominant data that has been used in the construction industry so far is rather less accurate. Moreover, the conventional methods of data acquisition are based on fieldwork that is time-consuming, expensive and labour-intensive. Accuracy of original data and efficiency of data acquisition could be enhanced using new lidar technologies. Lidar is the advanced remote sensing technology that is able to provide 3D data with centimetre to millimetre level accuracy effectively and efficiently. However, the implementation of 3D data for accurate as-built creation is still challenging especially for openings and fine details of the construction objects in an indoor environment. This paper presents a framework for rapid as-built modelling using 3D point cloud data captured by a handheld lidar. The procedure involves five key stages from data capturing to create a final model. This paper reports the implementation of the framework using the state-of-the-art mobile lidar to analyse fine details of a sample building. Lidar data of a sample building in an indoor environment is captured using a mobile laser scanner and is analysed after registration and segmentation processes. The reconstructed model using the as-built data is compared with the existing 2D AutoCAD plans of the sample building and the traditional measurements in order to verify the accuracy of the proposed method. The results of this on-going study confirm that the proposed model development technique can serve as a reliable tool for accurate development of rapid as-built building models (rABM). The accuracy ranges from 5 to 30 mm, depending on the object size and position. The proposed algorithm was shown to be highly efficient in identifying the main visible components in the buildings.

INTRODUCTION

New technologies such as 3D laser scanners and building information modelling (BIM) offer great possibilities in the construction engineering area (Love et al. 2014; Porwal and Hewage 2013; Volk et al. 2014). Since the new technologies have rapidly emerged, the clients and policy makers motivate and push construction engineers to adopt the technologies in order to increase the accuracy and speed of the as-built generation process. According to the Government's Construction Strategy of UK, the "government will require fully collaborative 3D BIM as a minimum by 2016" (Hampson and Brandon, p.14) with all documentation and data being electronic in projects. Similarly, the Building and Construction Authority (BCA) of Singapore implemented a roadmap that aimed at 80% of the construction industry using BIM by 2015 (McCoy et al. 2006). Generally, the future is to strive towards fully collaborative 3D BIM in other leading industries such as the Australian construction industry (Bell et al. 2010).

Recently, researchers have developed and introduced new models for as-built construction as the traditional process of documenting information has often been inaccurate and time-consuming. Tang et al. (2010) and (Volk et al. 2014) reviewed the current literature on building information regarding as-built and laser scanners. They discussed creating as-built BIMs and relevant modelling methods and algorithms. Their evaluation shows that the current literature largely ignores the investigation on data capturing but focuses on data processing which was carried out by researchers like Tzedaki and Kamara (2013) and Tang et al. (2010). These studies assume that there is a standard or unique algorithm, hardware, and software for data capture from scanners. This paper focuses on the process of capturing data in an original way using the handheld lidar, and then develops and presents a novel framework for rapid as-built modelling. The background to the as-built and its importance is discussed in the following paragraphs.

The U.S. General Service Administration (GSA) has commanded that every federal facility must be documented in 3D. GSA's Office of the Chief Architect (OCA) encourages their projects to use 3D laser scanning technologies as a prominent vehicle for acquiring building spatial data (OCA 2013). However, the current practices' accuracy still needs to be improved for as-built documentation purposes (Giel and Issa 2011). However, collecting and incorporating reliable as-built data as an essential for BIM is still challenging considering accuracy, time and cost constraints. According to Giel and Issa (2011), there is a great disconnection between the data derived from remote sensing and the creation of as-built using BIM.

In order to generate as-built models, previous technologies used to capture the data of the constructed objects once the whole construction work finished. It is difficult to scan all tasks before they are covered by another item stage to stage. Because the surveying-quality scanners are relatively expensive, it is difficult to adjust and relocate the tool through the construction site even by high skilled technicians. Hence, the detail and specification of many construction objects that are either left behind walls or buried for another scheduling could not be detected. In a traditional method, contractors take photos, make handy sketches, and log the object dimensions to record the objects before they are covered by another finishing layer. At the end of the project, companies recall changes and orders, shop drawings and documents which are developed for staging information. 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 parties has been well documented. On the other hand, 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 a solution to collect and record the completed construction objects for an as-built purpose, the effort to automate the process of an as-built creation on time is still in the early stages (Tang et al. 2010). Furthermore, there is still much work needed to improve the accuracy of the current practices considering cost and time in construction (Giel and Issa 2011). Particularly, integration of the data into BIM as a new paradigm of a knowledge sharing system is still challenging as the use of appropriate hardware, structure, and ad-hoc algorithm is still unachievable.

Using the high technology sensors, the process of as-built could change the process of data collection resulting in higher accuracy of the data in real time. This could enable construction managers to report accurately step by step for BIM. In spite of the accuracy and automation of current technologies, they cannot scan every place in the construction in detail. Research to develop a technology and procedure to make it possible to scan anywhere e.g. the built areas such as behind layers or underground performance is necessary.

This on-going study aims to provide a procedure 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 (ABM) using the state-of-the-art spring-mounted 3-D range sensor technology. The paper briefly reviews existing techniques for creating as-built which are mostly manual processes; and identifies technology gaps and barriers to the automation process. Then, the initial stage of the model is verified using independent data of a sample building at the University of New South Wales, Sydney, Australia. Finally, future work focusing on the validation of the model for other sample buildings and the plan for new practices for industrial or underground buildings will be presented.

MODERN METHODS OF AS-BUILT CREATION

Light Detection and Ranging (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.

Table 1. Comparing three As-built Approaches

Characteristics	Traditional Approach	Modern Methods	
		Early Modern Technologies	*r*ABIM (The present Model)
Hardware	Tools	Adjusting Scanners	Without Adjustment
Portability	Hand held	Bulky	Hand held (<1 Kg)
Required skill	Low	Medium-high	Low
Equip. cost	Hundreds	Tens of thousands	Thousands
Resolution	Hundreds of pt.	Millions of pt.	Millions of pt.
Accuracy	Centimetre	Millimetre	Millimetre
3D Modelling	Manual	Automatic meshing	Automatic

A considerable amount of research provided techniques to address the problem of recognition of interior and exterior objects in construction (Tang et al. 2010; Volk et al. 2014). However, there is no single technology which accomplishes all aspects of the process of volumetric representation and BIM. Corresponding to the challenging problem of reliable data collection of constructed objects in a timely manner, several studies developed techniques and technologies in remote sensing and surveying, however, they focused only on sharing collection information.

METHODOLOGY

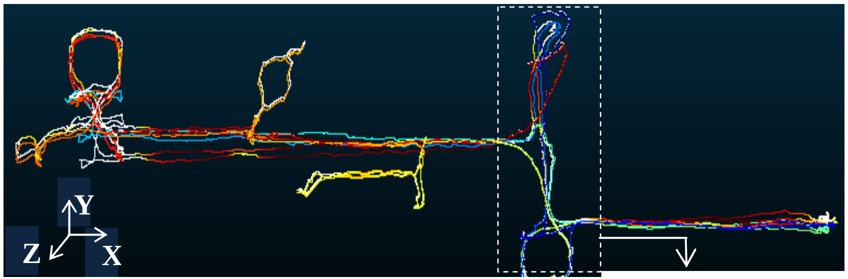
(a) Frame Work: Using new technologies in corporation, innovative algorithms assist us to create semi-automated and rapid As-Built Model (*r*ABM) for buildings in each stage of the project. With this intention, this paper attempts to take the first step forward to develop the model to create more accurate 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 *r*ABM. The *r*ABM is elaborating and verifying in an on-going study in order to assist the construction industry to benefit from the advantages of the new technology. The *r*ABM consists of five stages called data capturing, data processing, polygon extraction, making volumetric rABM and as-built modelling (ABM) and finally BIM. In this paper, creation of *r*ABM from Stage 1 to Stage 4 will be applied and the results will be illustrated in the following section.

In the data acquisition step, one building at the Kensington Campus of the University of New South Wales has been scanned using the mobile mounted range-sensing system. In the next stage, 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 to be used as identified as-built elements. Field work was conducted to assess and verify the level of accuracy obtained using the dense lidar points.

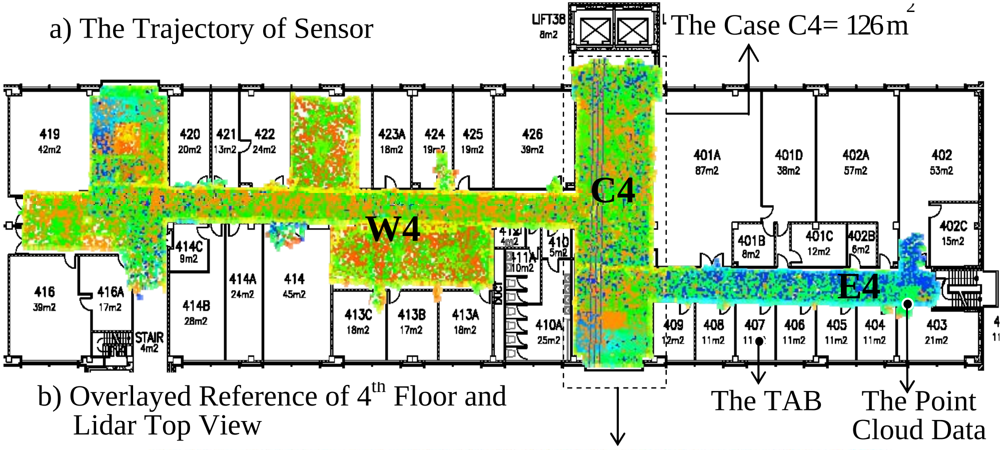
(b) Device and algorithm of data acquisition: First of all, the data was captured utilising a handheld mobile mapping device including lightweight lidar scanner. The utilised device is a 3D sensor system that consists of a rotating and trawling 2D lidar and a MicroStrain miniature internal measurement unit (IMU) mounted on a spring mechanism. The laser of the scanner is a Hokuyo UTM with 270-degree field of view, 30-m maximum detectable range. The dimensions of the laser chamber/box are 60×60×85 mm with about 200 g which is light for a construction operator. The six-degree-of-freedom (6-DOF) motion of the sensor head was accurately estimated by the system. The spring has a length between 50 and 150 mm. 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 applied 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 cloud was generated when the scanner was waved by hand and moved twice around within about 90-100 cm 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. The area has a lot of detail such as doors, windows, and stairs. This study area was selected as it is complex enough to explore the accuracy of the work for different architectural elements.

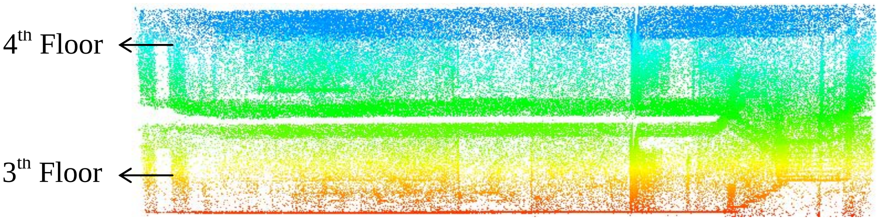
Indoor points of the study extent were scanned using an algorithm of acquiring points that takes advantage of recording points against a trajectory route and other points. This algorithm is capable of measuring thickness of the interior partition walls that will be discussed in the results section.



a) The Trajectory of Sensor



b) Overlayed Reference of 4th Floor and Lidar Top View



c) The 3D View of the Lidar Data (C4 and C3)

Figure 1. The Data and the Case Sample

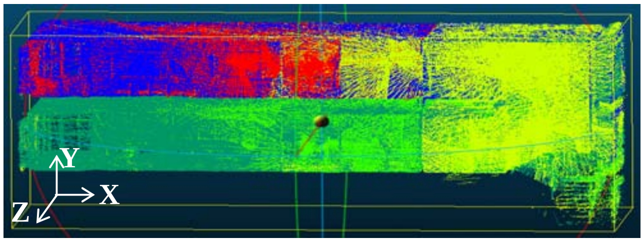
(c) Details of Study Extent: According to Tang et al. (2010), the majority of existing work focuses on the simplest elements of a building rather than details in their geometry where those elements are not yet captured. A reference map of the fourth floor exists to match with lidar points. The general attributes of the case study are represented in Table 2.

The study extent is divided into three main parts of the 4th floor as shown in Figure 1. For consistency in understanding the analysis, pseudonyms are used for the parts such as W4 to refer to the west wing; E4 refers to the east wing, and C4 to refer to the middle corridor of the 4th floor which is being studied. The letters with extension 4 stands for the 4th floor. In this paper, cases which are different in geometry, material, decoration and design are selected to investigate. It took about 20 minutes to scan the indoor environment of 2 levels of the building using the handheld rapid-laser mapping system that weighs slightly less than 700 g. Figure 1 illustrates the trajectories, layout plan and point cloud from the inside that were collected from the 3rd and 4th floors including W4, E4 and C4 of the sample building. The point cloud segment of 4th floor is overlayed on the layout plan of the same place to illustrate the area as shown in Figure 1b. The whole point cloud data from 3rd and 4th floors that are captured for this study is shown in Figure 1c.

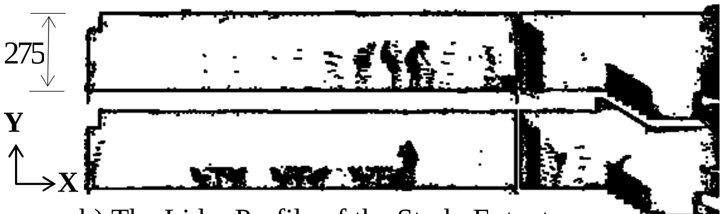
Table 2. Specifications of the Case Study and the Segment C4

Attributes	The Case	C4
Location	Randwick, Sydney	The middle corridor of 4th floor
Use	Higher Education	Meeting Area, Crossing Corridors
Type	Completed Construction	In use and Decorated
Scope	4-Storey Building	4nd Floor
Materials	Mix	Glass, wood, steel and concrete
Point	27,000,000	7,257,030
Scan Time	20 min	5 min

(d) Data Processing: A segment of the data from the north-south corridor of level 4 called C4 is selected to analyse as shown in Figure 2. Using segmentation technique, the 3D point cloud of this area was analysed to get the dimensions required. The open loop trajectory is shown in Figure 2(a). In the current practice, registration is still a semi-automated process. Data processing is also a semi-automated process that includes manual and automated filtering to remove unwanted data, such as points from moving objects and reflections.



a) The Processed Data

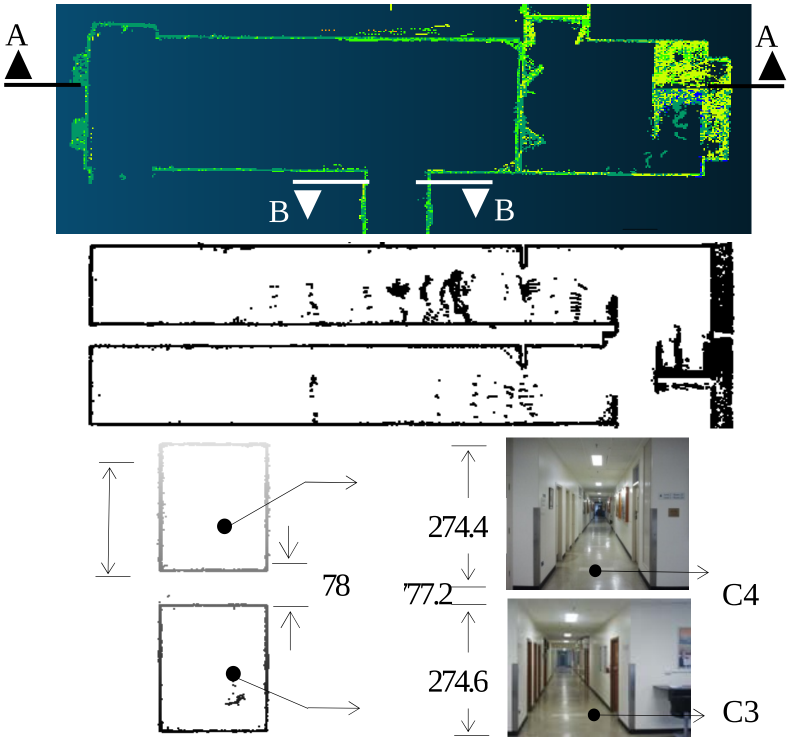


b) The Lidar Profile of the Study Extent

Figure 2. The 3D Cloud Points and Sections of the Case Study

RESULTS

This study aims to develop a framework for rapid as-built modelling using 3D point cloud data captured by a hand-held mobile lidar. This study also aims to implement the proposed framework using the state-of-the-art mobile lidar to analyse fine details of a sample building. Lidar data of indoor environment is captured using a mobile laser scanner and is analysed after registration and segmentation processes. The result of the model using the as-built data is compared with the result of traditional measurements and existing 2D AutoCAD plans of the sample building. In order to get three key dimensions of the constructed area, two sections are considered in the selected area called A-A and B-B as shown in Figure 3. All dimensions are in centimetres.



a) The C4 Floor Plan from Lidar

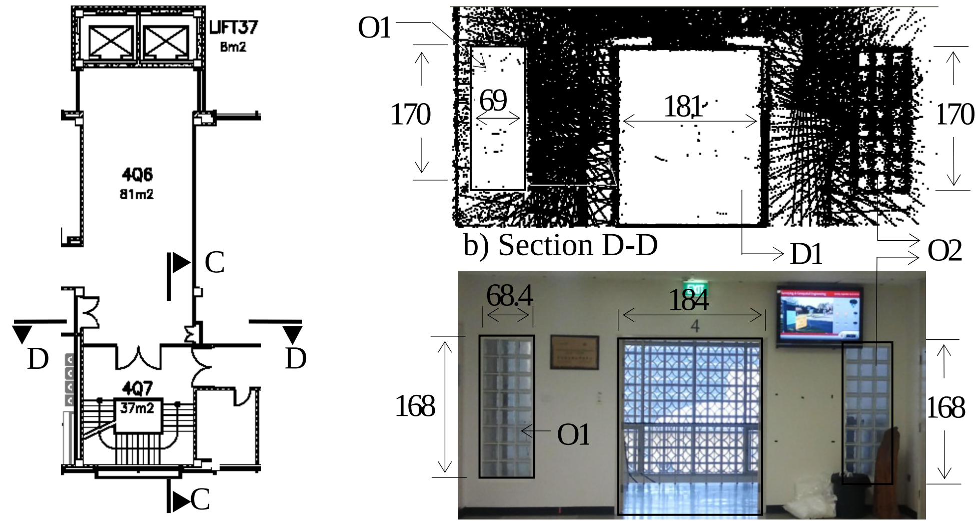
b) Section A-A from Lidar

c) Section B-B from Lidar (left)

d) C3 and C4 Side Views for TMM (right)

Figure 3. The 3D Dimensions of C4 and C3

The result of rABM for the entrance of the corridor E4 is illustrated in Figure 4 comparing the dimensions resulting from (Traditional Measurement Method) TMM which shows 2 cm errors. Figure 4 illustrates some of the measurements which are shown in the C4 floor plan. The illustrated objects include openings (i.e. O1 and O2), stairs (i.e. section c-c), stairs handrail (Figures 4d), and partition thickness (Figure 4d). The difference between *r*ABM and TMM for the thickness of interior wall is 2 cm (Figure 4d). The *r*ABM and TMM results for the handrails shown in Figure 4d are about 2mm. The average of differences for stairs is 2 cm.



a) The C4 Floor Plan

b) Section D-D

c) The D-D View

d) Section C-C from Lidar Data

e) The C-C View

f) The Details from Lidar Data

Figure 4. The Details of Openings and Stairs

Fieldwork was conducted and the results compared to that from the point cloud (Table 3). The accuracy of the boundaries of the openings ranged from 5 mm to 30 mm which is highly accurate, compared to the previous practices.

Table 3. The Results for rABM Comparing the TMM

Scope of the Object	Case	Location	*r*ABM (cm)	TMM[1] (cm)	Error (cm)	Accuracy[2] (%)
Window (O1)	O2-CL	C4	170	168	2.0	1.17
	O2-CW	C4	69	68.4	0.6	0.87
Window (O2)	O1-L[3]	C4	168.5	168	0.5	0.29
	O1-W[4]	C4	68	68.5	-0.5	0.73
Door (D1)	D1-FL	C4	203	205.5	-2.5	1.23
	D1-FW	C42	181	184	-3.0	1.65
Stair	WL	C4-C3	27	28.5	-1.5	5.55
	WW	C4-C3	15	16.7	-1.7	11.33
Ceiling (T1)	T1	C4-C3	78	77.2	0.8	1.02

[1] TMM: Traditional Measurement Method which we used the surveying tools to manually control the dimensions.

[2] Accuracy = (Error/rABM)×100; [3] L refers to the length of the object; [4] W refers to the width of the object.

Modelling the openings is still challenging. Therefore, we focused on processing openings (i.e. O1 and O2). According to (Tang et al. 2010), the majority of existing modelling work focuses on the simplest elements such as walls. They reported that there is still a gap in modelling complex elements and openings such as doors and windows. In addition, they stressed that fine details such as decorative and window details should be worked in the long term future. In the current practice, we also worked on decorative items such as partitions and stair handrails.

MODELLING AUTOMATED *r*ABM

We envision a robotic tool that could navigate through the construction object, capturing data and then the automated system produces a highly accurate and semantically rich ABM. In the geomatics community, many researchers have studied the problem of mapping outdoor and, less often, indoor buildings. The main distinction between our work and prior research is that the capturing process is very fast and easy without any stations inside or outside the object.

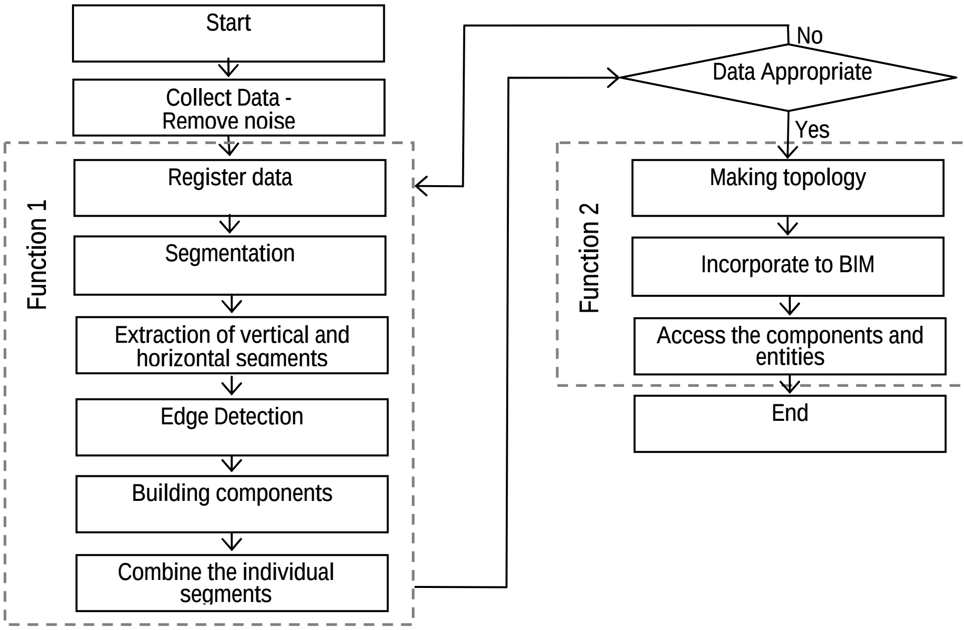


Figure 5. The Flow Diagram of the Algorithm for rABM

The applied sensor, and consequently the algorithm are totally different from existing work which enables us to develop a segmentation model as shown in Figure 5. On the other hand, the prior robotics applications are typically concerned with navigations and detection algorithm; whereas the proposed study focuses on the performance quality of the As-Built creation such as accuracy, speed and cost.

CONCLUDING REMARKS

The need for efficient real-time data acquisition systems has recently attracted a great deal of attention in construction. In this study we developed a novel framework to increase the speed of creating as-built models. This paper employed a new procedure of mobile hand-held lidar for indoor mapping in order to propose a new easy-to-use, fast and robust process for an as-built creation called *r*ABM. The 3D lidar scanner technology is 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 get real dimensions of one complex building.

The capture of raw data took about 20 minutes for the whole indoor environment of two levels of a building using the state-of-the-art technology. The weight of the handheld device is slightly less than 700 g and it does not need a fixed location or stationing. The current terrestrial scanner needs to scan from different locations which may take about 15-20 minutes for each location. In addition, dimensions given by the new technology are verified using the traditional measurement method and the results are more accurate than the current as-builts which were created by a construction team. Surprisingly, the initial results of the process show that the accuracy is higher than the previous work at some areas such as openings, fences and stairs. The current method could cover the weakness of the previous work because, for example, the accuracy of the dimensions for openings in the previous work remained lower than the construction needs.

This study shows some significant potential benefits that can be improved by integrating the data capture with a structured BIM approach to engineering design. However, there is much work to be done to automate the whole process of as-built creation in construction. In addition, the 3-cm level of accuracy raises the question as to whether or not the pipes and electrical objects in the building can be measured using this advanced technology. The main objective of the next phase is to fully automate the process and expand the potential applications of the mobile lidar technology.

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