Challenges and Opportunities for Implementation of Laser Scanners in Building Construction

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Abstract –

Digital technologies, including hand-held laser scanners and locating systems, are being increasingly introduced to the construction market and have the potential to provide real-time data to create construction information modeling (e.g. shop drawings and as-built). Focusing on the unique advantage of these technologies, this paper identifies the challenges and opportunities for implanting such technologies to create multi-dimensional information modeling based on updated data from construction objects. The results of the paper will be based on implementation of a proposed framework to assist in semi-automated conversion of the raw 3D point clouds from advanced scanners into a compact, semantically rich model aiding in updating construction drawings and developing as-built models. A couple of advanced laser scanners have been deployed within an educational building and have scanned a floor as a sample in order to collect the data. In addition, further data was collected using novel positioning systems, to generate updated data from objectives and labor working in the sample area. The findings show that mobile laser scanners and the novel locating system are efficient tools for updating data to assist construction and maintenance managers to revise the drawings and use updated multi-dimensional models, and are about 50% less expensive than the current technologies. It was found that the practical framework - using mobile laser scanners - enables construction managers to acquire updated information from complex objects, using a real-time communication system. The study provides a step towards understanding the possibility of implementing advanced technologies and internet-of things in construction, and assisting in developing a shop drawing revision modelling for construction purposes.

Keywords –

Laser Scanner, Implementation, Challenges, Ease of Use, Building Information Modelling, Drawing.

1 Introduction

There is a desire to generate digital just-in-time information in construction for management purposes, and to convert all construction documentation to an electronic edition compatible with other software and existing information molding. The emerging technology such as laser scanners coupled with positioning systems provides an opportunity to move forward to a cost-efficient way of generating required information in construction and also in digital as-built creation. Many governments encourage construction engineers to use digital 3-dimensional (3D) documentation in BIM, for example: The United States General Service Administration's Office of the Chief Architect [19], Singapore, the UK, and Australia. However, the current practices' accuracy, possibility of acquiring data from complex objects indoor and outdoor, and skill required to work with the data needs to be improved for as-built documentation purposes [10]. 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. 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.

This paper aims to identify challenges and opportunities for using laser scanners and locating systems in construction. Based on the findings of the paper, a discussion will be provided to the scanner adoption factors, the future of digital technology usage in construction. The main objectives of this paper are: 1) to analyze the result of implementation of mobile scanners to generate accurate data from construction site; 2) to examine the feasibility and challenges of using new scanners and positioning systems to capture data in construction.

The originality of this paper lies in providing an insight to new technology implementation based on experiments applying cutting edge hand-held scanners for real-time indoor data acquisition. The generated data also enables contractors to create and/or update the construction information modeling in a cost-efficient and timely manner.

The paper firstly reviews existing technologies for creating information modeling including as-built models as an example, which are mostly manual processes; and identifies technology gaps and barriers to the automation process. Secondly, the results of applying the advanced technologies to provide independent data sets of a sample educational building at the University of New South Wales, Sydney, Australia are briefly presented. Thereafter, the challenges and opportunities of using such technologies in construction projects will be discussed from a practical sense.

2 Updating the Construction Drawings

In any project, there will be a requirement to update the building objects dimensions where they were changed during construction based on the consultant change orders or as a result of clash management. This mainly is covered by as-built information modelling. The process of as-built information modelling using new technologies can be divided into two main phases: data acquisition and building information modelling. The data acquisition method is the focus of the study.

Several techniques can be used for data acquisition in order to create as-built in construction. However, there are limited techniques for acquiring data with the possibility for creating digital 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 laser scanners are an accurate and fast solution that will be employed in this paper. In order to solve these problems, we will use a novel mobile equipment to acquire data.

2.1.1 The Current Manual Methods

The manual as-built practices are mainly based on graphical standards for 2D drawings [6]. 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 [11]. However, this traditional method of data acquisition produces a mass of drawings that makes their management and usage time consuming [15]. For example, Wang and Love [33] explain that traditional site layout method is labor intensive and required many times re-measuring.

Historically, sketches 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 [13]. Recently, researchers have tried to use photogrammetry techniques to produce digital and parametric data for as-built information modelling. Photogrammetry refers to geometric information derived from photographs [37]. However, this method has limitations [3,14]. For example, extracting object points from a wide angle shot near an object is difficult [14]. This approach is unable 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 [17]. Recent studies attempt to integrate digital photogrammetry with lidar scanners [13,16].

2.1.2 Laser Technologies

Light detection and ranging (lidar) is a laser imaging technology that is increasingly employed for capturing scenes with millimeter to centimeter accuracy. 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. The fact that laser scanners collect 3D data gives it many advantages over the 2D methods such as using 2D plans.

New research studies intend to use laser scanners for construction purposes [7,35]. For example, several studies attempt to use laser scanners for as-built creation [27,36]. However, there are two main problems in this area. First, geometric information such as lines and surfaces cannot be easily extracted from millions of points data of objects [1], and are recommended as future research [1,4]. Second, a limited number of scanners such as terrestrial scanners are suitable for BIM [36], and the state-of-the-art technologies have not been investigated fully.

2.1.3 Gap in using the generated information

Building Information Modelling (BIM) is a collection of data which digitally represent the relevant characteristics of a building [34]. 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 would not be very useful if it only represents the design, as it currently occurs. The data platform has the potential to be fully used during construction as well as through the building maintenance life cycle. However, the challenges of generating new information that originated during construction, and updating the data or providing just-in-time information are barriers of the current practice. 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 [12]. The capabilities of BIM as a representation model and its requirements for as-built BIMs are well investigated [5,8,9,20]. However, Huber et al. [12] claim that the topic of representing as-built BIM is in its early stages. Furthermore, current procedures rely on manual processes which are labor-intensive, time consuming and susceptible to errors [28]. According to Tang et al [28] existing work focuses on modelling the simplest objects of a building rather than modelling complex objects such as doors and windows. In addition, they show that there is a significant disconnect between surface based modelling and volumetric modelling representations[28].

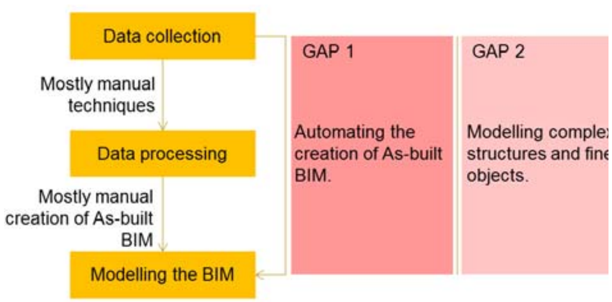


Figure 1 Schematic of the gap in scanner usage

Figure 1 schematically represents the literature divided into three main categories: data collection (input), data processing, and modeling (output). The literature shows that studies examining new technology applications to acquire input data for creating as-built BIM are scarce. However, much study focused on modeling and the output of modeling [2,32,33]. This paper examines a novel mobile laser scanner to create as-built BIM in construction.

In summary, the review reveals four significant challenges for creating as-built BIM. First, previous work mainly used terrestrial scanners and fixed lidar equipment [8,9,12,28]. Using state-of-the-art technologies have been totally ignored. Second, modelling fine and complex objects of buildings have received little attention [12,28]. Third, a procedural approach toward automatic as-built creation of the entire building is still unachievable [8]. Forth, the integration of laser scanner technologies with photography techniques and positioning systems to acquire much rich information model has not been covered in the literature.

3 Research Method

3.1 Case Study for Experiment

The experiment has been carried out in an educational building at the University of New South Wales, Sydney. The sample area chosen is the fourth floor as shown in Figure 2. The area includes different objects such as openings and stairs making it complex enough to explore the accuracy of the work for different building elements. For example, modelling such fine objects and details are still challenging. The general attributes of the case study are represented in Table 1. 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 fourth floor which is being studied.

3.2 Data Acquisition Methods

Using new scanners in corporation, a procedural framework was employed to assist in creating drawings documents. The paper attempts to identify the challenges and opportunities of using the employed scanners and positioning systems by utilizing the scanners to create more accurate as-built with low skill labor in a shorter time. Based on the literature and previous work [22,24,26], the overall process for as-built creation is proposed consisting of scanning, processing, and creation [22].

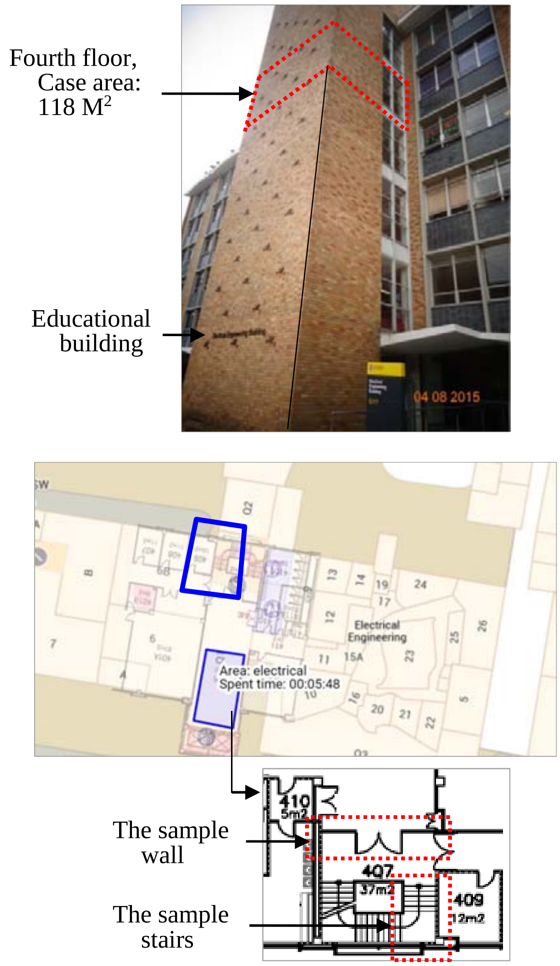


Figure 2 Location of the case study and the sample area (blue area detected by a chosen locating system)

In addition, the algorithm and feature of the new hand-held mobile scanners which are used in this paper dictated the procedure to follow to create the information modelling. The procedure is a part of an on-going study in order to be fully implemented to create as-built models to gain benefit from the advantages of the new scanners. The procedure consists of four stages as follows:

In the first stage, different scanners were used for data capturing, data processing, polygon extraction, making volumetric shapes and creating an initial information model. The implementation of this stage is presented in this paper, and the challenges and suggestions are discussed in the following sections. In the data collection step, one mobile mounted range-sensing system, one mobile hand-held scanner, and two terrestrial scanners were used. 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 scanner points. In this stage, the results of the mobile scanners were compared and verified by a data set acquired from the terrestrial scanners.

Table 1. The case study details

Items	The building case	The sample area
Location	Kensington	The north-south corridor
Use	Higher education	Crossing corridors
State	Renovated	In use and decorated
Scope	Architectural objects (e.g. window and door)	The partition wall
Materials	Mix	Timber, glass, steel and concrete
Point cloud size	10 to 30 millions	5 to 7 millions

In the second stage, a digital camera was used to collect complementary information about the texture and color. In the data acquisition step, the sample area has been scanned using the scanners.

In the third stage, the information collected from previous phases including point clouds and photos were analyzed and the topology for information modelling was made. In this phase all data should be incorporated to produce a rich model. The model should also update epoch by epoch analysis when the shop drawing needs to be updated.

In the fourth stage, the modelled objects and other information such as colors and positions will be collected in an integrated system to measure the progress. This part of the algorithm is designed but will be examined in the future study.

3.3 Device for Data Acquisition

Four advanced laser scanners including a novel handheld mobile scanner, DPI mobile scanner and Leica scanners were used to implement the framework. The first device is a mobile scanner capturing data by utilizing a handheld mobile mapping device including a lightweight scanner. The utilized device is a 3D sensor system that consists of a rotating and trawling 2D scanner and a MicroStrain miniature internal measurement unit (IMU) mounted on a spring mechanism. This technology was used because, in contrast to stationary terrestrial scanners, it does not need a tripod or a vehicle or skilled operation. Indoor points of the study's extent were scanned using an algorithm of acquiring points that takes advantage of recording points against a trajectory route and other points.

The other data set was collected using a state-of-the-art scan- and multi-station 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. Similarly, another terrestrial scanner was also used to collect the third set of the data in order to verify the results. Figure 3 shows two views of the partition wall using Leica C5.

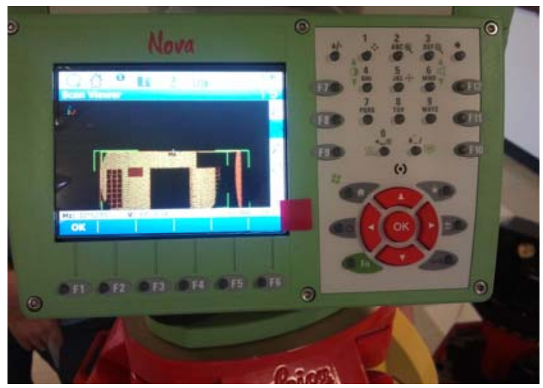
3.4 Data Process

Scanning the indoor environment of the fourth floor of the building using the handheld laser scanner took about 10 minutes. The point cloud segment of the fourth floor is overlaid on the layout plan of the same place. Using segmentation technique, the 3D point cloud of this area was analyzed to get 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.

The multi-station terrestrial scanners (Figure 3) were required to be adjusted at two locations. The process of data collection took about 30 minutes from two locations including stationing and scanning. This data collected by terrestrial method contains fewer noise points compared to the handheld laser scanner.

The segmentation is used as the first technique for preprocessing. This technique is used in order to get comparable results. The same segment of point clouds including the wall in the corridor, two windows, one door and couple of stairs behind the door were selected and processed. Processing of the data sets consists of conversion of the text files to ply and las files for visualization purpose. Then, detection and reduction of noise (unwanted objects such as people and furniture) was carried out. 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. Extending previous work [22,24,26], the examples of initial results are shown in Figure 4. Two segmented components: wall (including windows and an opening) and a section of stairs of the sample C_4 were modelled. Levels were allocated in components and a model was created.

a) Mobile Scanner



b) Tresstiral Scanner

Figure 3 Selected and Utilized Terrestrial and Mobile Scanners

4 Findings and Discussion

In this section the results of experiments will be used to identify how ease of use is the result of implementation of the advanced technologies in construction. Ease of use is one of the main advantages of a new information technology [29]. The implementation attributes including ease of use of a new technology are critical measurements of technology adoption in construction [21,23,25]. The reason is that the construction industry is a naturally low-skilled labor based industry, and they are less likely to use complicated technologies. However, ease of use has not been yet examined specifically on laser scanners and location systems in construction. Thus, the discussion of this section provides a totally new insight in predicting advanced scanner adoption in construction. The result of the study will appeal to scanner manufacturer and vendors as it shows how ease of use concept can be applied to each type of scanner.

The results of using the advanced laser scanners and a location system in the same area (educational building) were compared and evaluated as follows. Previous studies mostly focused on the feasibility of using a specific terrestrial scanner to acquire data for information modeling. This paper utilized both terrestrial and mobile scanners and compares their performance. The performance evaluation was carried out across five main determinates as shown in Table 2.

Lidar result demonstrability (LRD) – All advanced terrestrial scanners and the DPI mobile scanners used in this study, demonstrate the objects when we were scanning the area. However, the first hand held mobile scanner was not able to demonstrate the three dimensional object when scanner meaning that the operator would not get an understanding of whether the whole area had been scanned or not. But DPI shows what has been detected and the relevant point clouds will be saved and available for further analysis. When we moved the mobile scanner very quickly, the scanner was not able to detect and create point clouds and a message appeared that the object had not been detected.

Lidar output quality (LOQ) – The results show that the terrestrial lidar scanners are more accurate than mobile lidar scanners in most cases, and from visual inspection fewer noise points can been seen in the terrestrial scanner data than in the mobile scanner data. The results show that the accuracy of the result of implementing handheld mobile and terrestrial scanners are 25 mm (i.e. from 5 to 30) and 11 mm (i.e. from 1 to 12) respectively. According to Randall (2011), the accuracy for construction site monitoring and structural analysis and inspection should be less than 10 cm and 1 cm respectively. Thus the output quality of scanners is accurate for construction purposes. Randall (2011) also reports that the distance of scanner to target should be less than 25m and 10m respectively as well. The accuracy of the result of implementations of the frameworks using terrestrial scanner (#2) comparing traditional measures varies from -2% to +2% for openings, while this accuracy for the other experiments vary between -3% to +3% and from 1 mm to 12 mm. All in all, the results show that the terrestrial lidar is more accurate than the mobile lidar in most of the cases.

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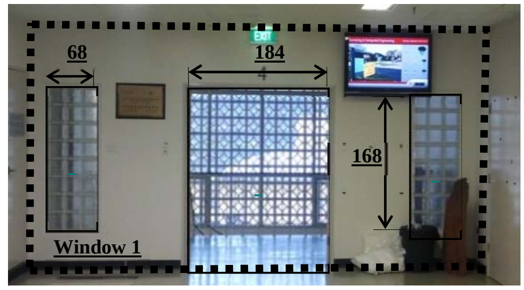
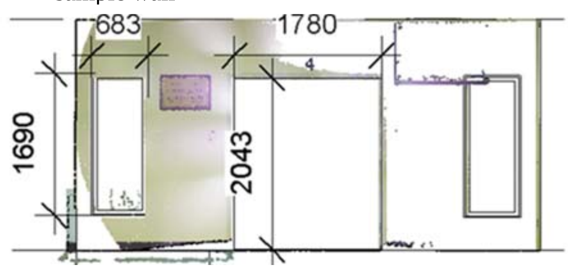


a) Traditional measurements of objects of the sample wall



b) Segment A – A in BIM [24]

Figure 4 The segments and modeling of the sample partition

Lidar objective usability (LOU) – the data collection process of the terrestrial scanner is not as fast as the mobile scanners. The results of the mobile scanners also showed that they were not able to scan fine objects in a short time. However, for scanning small objects where high accuracy is required, we recommend the use of terrestrial scanners. For larger objects, where the contractor needs quick results, mobile scanners are more suitable with low cost in operation and ownership. Further analysis applied on the measurements of doors and windows, and errors for the opening dimensions were calculated. Standard Deviation for these three residuals for handheld scanner and terrestrial scanner 1 and 2 are 19.3, 26.3 and 1.9 mm respectively. The findings show that terrestrial scanner 2 has a large difference than others for scanning openings, and gives better results than others in this sample.

One type of scanner cannot be used alone for collecting the data from all construction objects. For example, it is impossible to move a terrestrial scanner inside the building during construction because of many obstacles. The experiments show using both mobile and terrestrial lidar scanners can be more helpful for the shop drawers in order to create a mature model and easily update the documentation during construction.

Table 2. Evaluation of lidars' ease of use

Determinant/ Reference	Definition	Results
Lidar output quality (LOQ) [30]	The degree of the scanner performance for doing the job.	Yes (between -2% to +2% accuracy)
Lidar result demonstrability (LRD) [18]	The degree showing that the results of using a scanner are tangible, observable, and communicable.	Yes/No
Lidar objective usability (LOU) [30]	A "comparison of systems based on the actual level (rather than perceptions) of effort required to completing specific tasks".	Yes/No
Lidar job relevance (LJR) [30]	The degree of applicability to as-built creation.	Yes
Lidar external control (LEC) [31]	The degree of the affordability of availability of resources to support the use of the scanner.	Positive/Negative

Using conventional scanners can barely help us to get the texture and color of each object. In particular, many materials have similar colors. So, using digital photos can assist shop drawers to increase the level of BIM maturity by adding the information collected from photos. However this practice was a manual one and needs further research to develop an automated procedure to decrease the errors of data entry for large projects.

The experiment shows that there are difficulties in scanning indoor objects by terrestrial scanners, because there are many obstacles, particularly during the construction period when many people and machines move around the area.

The experiments show that the process of integration lidar and other technologies (e.g. location systems or photogrammetry) needs much work to be semi-automatic. However, the integration practice is useful for a contractor to collect more information using a unique framework. 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 terrestrial lidar equipment is not possible.

Lidar job relevance (LJR) – The experiments show that all of these scanner technologies are applicable for updating design drawings and creating as-built drawings. However, as construction sites are a congested area with equipment and a labor force often moving around, using terrestrial scanners provides more noise point clouds compared to mobile scanners, because the user is able to control a mobile scanner to move away from disruptions. In fact, using terrestrial scanner technologies will produce more noise as they cannot be moved when something passes from in front of the scanner while the scanner is automatically detecting the object. Mobile technologies, in contrast, can be moved when there is an object in front and are flexible enough to vary the distance from the object.

Lidar external control (LEC) – Another difference between the mobile and terrestrial lidar is the external factor of 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 commercialized. A summary of the comparison of the two experiments is listed in Table 4.

5 Conclusion

This study aimed to identify the challenges and advantages of terrestrial and mobile scanners for construction purposes. The paper employed a proposed framework consisting of five different determinants of ease of use in order to examine the performance of each scanner in construction. The results of four scanners' experiments were evaluated based on the five determinants.

The results show that lidar output quality (LOQ) for all scanners is acceptable for construction purpose as the accuracy varies and is less than 2.1%. However, Lidar result demonstrability (LRD) criterion has not been met by all scanners. Lidar objective usability (LOU) has proved acceptable for all scanners when the objective is as-built creation, but other construction usability of scanners is arguable. For example, there is much work to be done to implement the scanners in different fields and automatically develop a digital as-built model. Lidar job relevance (LJR) is acceptable for all scanners, while lidar external control (LEC) is arguable and will depends on organization affordability.

The comparison shows that mobile scanners are suitable for indoor buildings and can be used in conjunction with terrestrial scanners which are able to collect both outdoor and indoor data. However, there are many different complex objects in construction and mining, so future studies should examine LOU and LJR more specifically in terms of building complexity, size, volume, location and in extreme weather and conditions in construction, piping, tunneling, and mining.

The limitation of this study is that we did not repeat the experimentations in different conditions such as weather conditions. Future work should consider different factors such as factors that affect the scanners during their placement (e.g. height, distance and extreme weather conditions). 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. This study shows some significant potential benefits of the scanners from performance perspective (i.e. ease of use), that can be improved by vendors to increase the rate of technology adoption in construction.

Table 3 Cost per hour for each scanner

Scanner	Expenditure cost (A$)	Scanner hire cost per hour (A$)	Operation cost per hour (A$)	Process software cost per hour (A$)	Process cost per hour (A$)	Total cost per hour (A$)
T 1	78,000	260	16.6	5,000	150	83,427
T 2	65,000	216	12.5	5,000	150	70,379
T 3	25,000	83	4.1	5,000	150	30,237
M 1	11,000	36	6.6	5,000	150	16,193
M 2	22,000	73	1.6	-	400	22,475

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