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A Scanner Technology Acceptance Model for Construction Projects

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Abstract

Acquiring 3D building geometries is crucial for rapid energy exchange modelling of buildings. With a significant potential to contribute to high-performance built environment, positioning systems and laser scanners are being increasingly utilised to the construction industry for acquisition of 3D models of buildings. However, there are major barriers to successful scanner implementation in construction projects including a lack of knowledge about the scanner applications, low skilled workers and complicated data analysis processes. While many studies focus on general IT/ICT adoption in construction, there is a lack of understanding about the process of sensing technology adoption and its utilization in construction. To address the gap in the literature, this paper presents the Scanner Technology Acceptance Model (STAM) utilizing two main criteria; 'usefulness' and 'ease of use' each measured by a range of factors. The model is verified based on the result of the application of scanner and location system in a university building renovation project. The scanners were used to collect raw 3D point clouds to transfer into a compact, semantically rich models aiding in updating construction drawings. The findings show the effectiveness of the STAM. STAM enables technology suppliers to predict the technology diffusion rate, and helps the users to make decisions on choosing the right technology in construction projects. Further research based on this investigation will validate and enhance the model by using larger scale consultation and interview process, and this will be reported in a future research paper.

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Keywords: Sensing Technology; Laser; Mobile Scanner; Acceptance Model; Construction.

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1. Introduction

3D building models are required for environmental simulation [6], energy exchange modelling [4] and surface energy balance for a realistic urban canopy [20]. All these applications of 3D building models are crucial for sustainability assessment of the performance of buildings and urban developments. While there is increasing interest towards using laser scanners to collect lidar point clouds for 3D building modelling in BIM, there is a lack of evaluation of adoption of laser scanner technologies for construction industry.

The construction industry frequently reported as a low-technology industry [5,22,25,26] lagging behind other industries in terms of implementing any type of innovation [8,22,25,26]. However, in the recent years, there is an increasing motion to introduce new technologies into the construction industry which supposed to be useful for improving productivity and increase sustainability [14]. For example, there is a desire and also potential to generate digital just-in-time information in construction for safety management and updating all building information modeling (BIM). One of the cutting edge technologies, which is rapidly advancing can be categorized as sensing technologies such as laser scanners. The aim of this ongoing study is to develop the Scanner Technology Acceptance Model (STAM) that explains users' intention in terms of the technology attributes sustainability and social influence.

Laser scanners coupled with real-time locating systems provide an opportunity to move forward to a cost-effective way of collecting 3D geometries of buildings to be used for energy exchange modelling that is crucial for sustainability assessment of buildings performance. Many governments encourage construction professionals to use 3D digital documentation in BIM. For example, the United States General Service Administration's Office of the Chief Architect [16], and Singapore, the UK, and Australia are moving to that direction, too. Many vendors present a wide range of technologies to the construction industry. Since the digital market is compatible, the prediction of scanner technology acceptance is very important for vendors to evaluate the market for any specific new scanner. Previous studies in construction Amoako Gyampah and Salam [2]; Adriaanse, et al. [1]; Park, et al. [18]; Son, et al. [30]; and Lee, et al. [13] covered a wide range of technologies, but scanner customer behavior has not been pursued in construction.

This paper firstly identifies technology gaps and barriers to the scanner acceptance process in construction. Secondly, a novel conceptual model for predicting scanner technology acceptance by users in construction industry is developed. Thirdly, the two main types of lidar data acquisition technologies of terrestrial and handheld scanners are utilized and compared for 3D building modelling. Finally, the key factors influencing the scanner acceptance are identified and the scanner technology acceptance model (STAM) is developed to evaluate the performance of these technologies for 3D building modelling in BIM.

2. The Conceptual Model for Scanner Acceptance

2.1. Technology Acceptance

The technology acceptance process refers to a series of mental and behavioral states that a person passes through leading to the adoption or rejection of an innovation [12]. Davis et al. [10] establishes the Technology Acceptance Model (TAM) as an example of individual behavior prediction applying specifically to the field of information systems. This model can be used for a wide range of information technologies such as E-Collaboration Technology [9], Internet via mobile devices (WIMD) [15] and mobile technologies [17]. Ajzen and Fishbein's (1977) Theory of Reasoned Action (TRA) is the base of technology acceptance models in the information system disciplines, which has been used as a basis for technology acceptance models. Extending the TRA as a general psychological theory, the Technology Acceptance Model (TAM) [10] has been established as an example of individual behavior prediction applying specifically to the field of information systems. Two external constructs have been used as constructs of TAM: Perceived Usefulness and Perceived Ease of Use. TAM has been extensively used in many disciplines such as information systems, electronic devices and construction for describing information technologies' acceptance. Researchers such as Amoako-Gyampah and Salam [2],Venkatesh and Bala [33, p. 276] and Park et al. [19] have provided theoretical underpinnings of the relative important factors of the TAM in information systems. The researchers intended to extend the basic models in order to delineate uncovered measures of the main construct of the model. It has been extended by adding more construct determinants for actionable guidance and a more complete list of these determinants. For example, based on the synthesis of the previous efforts on TAM, TAM 2 [34] and TAM 3 [33] were developed by adding several determinants such as social influence and job relevance, image, quality and result demonstrability to the previous model. TAM 3 postulates that the effect of perceived ease of use on perceived usefulness will be moderated by experience. Around the same time, the Unified Theory of Acceptance and Use of Technology model (UTAUT) was introduced that unifies TAM and innovation diffusion theory [35]. UTAUT suggests determinants of intention and usage to predict the success for new technology introductions and understand the drivers of acceptance.

2.2. Acceptance of Laser Technologies

Light detection and ranging is a laser imaging technology that is increasingly employed for capturing scenes with millimeter accuracy. This technology is called Scanner in this paper. The main advantage of laser scanners compared to traditional 2D data collection methods is to acquire 3D point clouds with accurate X, Y and Z coordinates. New research studies intend to use laser scanners for a variety of different construction purposes and discuss the advantages of the scanners [11,21,24,27,28,36]. For example, several studies attempt to use laser scanners for as-built creation [21,24,27,28,31,37]. However, other studies discuss several main problems in this area. In addition, geometric information such as lines and surfaces cannot be easily extracted from millions of points data of objects [3], and are recommended as future research [3,7]. Another example is that a limited number of scanners such as terrestrial scanners are suitable for BIM [37], and the state-of-the-art technologies have not been investigated fully in terms of performance. While the advantages of this technology for construction have been proved in literature, there is a lack of understanding of laser scanners’ acceptance for various types of construction projects.

3. Method

In order to model factors influencing sensing technology acceptance, case study method is employed. Five case studies have been chosen to evaluate the capabilities of different cutting edge technologies. Based on the evaluation of the scanners, main factors are identified and used for modeling the scanners acceptance. Previous work shows that scanners provide dimensioning data in an accurate manner and within a short time frame [21,24,28].

The results of field experimentation using the scanner technology was undertaken in a real world data capture scenario, using a sample building at the University of New South Wales. A number of competing advanced technologies were tested including: two handheld mobile scanner (HMS); and three stationary terrestrial scanners (TLS) with different range including a multi-station and scan station model. The feature set of the competing technologies was analyzed with respect to onsite application and subsequent data conversion processes. The intention was to compare the performance of the scanners with camera combination, and their compatibility with photography approaches.

The utilized HMS included a 3D sensor system that consists of a rotating and trawling 2D Scanner and an internal measurement unit mounted on a spring mechanism. This scanner was utilized for its advantages to the stationary TLS. For instance, the HMS does not need a tripod or a vehicle and skilled operator. The handheld scanner utilized an algorithm for data collection that takes advantage of recording points against a trajectory route and other reference points. The HMS was transported through a loop in the corridor of an existing building on two floors. The area represented a lot of detail such as doors, windows and stairs. This study area was selected as it was complex enough to explore the accuracy of the different scanner technologies. The TLS options were used at two locations from less than three meters distance from the objects being measured. The maximum distance measurement and the maximum range were 50 and 1000 meters respectively for the TLS units.

4. Identifying Key Factors Influencing Scanner Performance

This section reports the results of evaluation of the scanners implementation in construction. Main factors associated to the scanners performance which may influence the scanner acceptance were identified based on the experimentations [27] as follows:

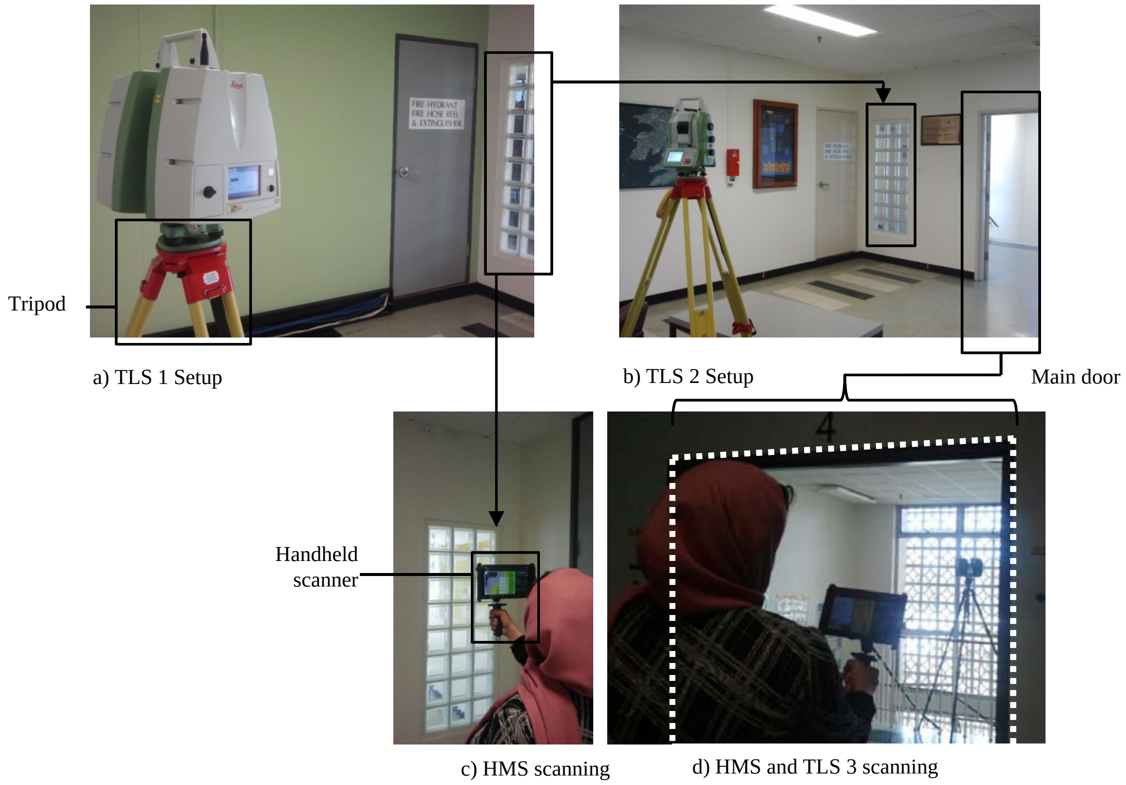
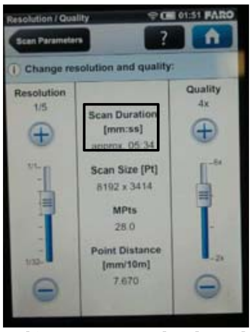


Fig 1. Terrestrial and handheld mobile scanners

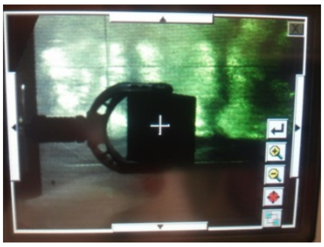
1) Setting up the TLS in different locations: As shown in Fig 1, TLS requires a tripod to setup and it must be moved multiple times to capture information from different angles. This is not the case for handheld HLS scanner. Indeed, moving the TLS and making adjustments is time-consuming and not particularly cost-efficient. In contrast, the experiment showed that using HMS enabled construction engineers to capture indoor data without any setup requirements. The operation time also is very quick and does not require skilled operators to capture data. Fig 1c shows that HMS is a more portable and cost and time-efficient option.
2) All TLSs are significantly more accurate where fine dimensional detail is required for the likes of fine grain positional or set out work.
3) Capturing RGB data in conjunction with 3D geometric data: Except TLS, other tested scanners were incapable of capturing the texture and colour of each object directly. This is a very important feature for construction industry, as many materials had a similar colour scheme.
4) Automating the integration of RGB and 3D point cloud data: since the process of integrating of the data from laser scanners with photogrammetry needs much work to be automated for the latter scanners, it is imperative to identify the challenges and barriers for automation of integrating 3D point clouds and RGB data.
5) Rapid scanning: scanning time was fast for the test area covering approximately 100 m^2. For instance, the TLS multi station used less than 20 minutes to capture a dense point cloud of the entire area, but of course this relies on fast post capture processes in order to ensure true efficiencies are properly realised.
6) Result demonstrability: the scan viewer of TLS also provides the possibility to see the scanned area during the scanning process. HMS cannot easily provide a view at the time of scanning.
7) Communicating between scanners and main server: The scanners cannot communicate real-time with other devices by itself. A Wi-Fi system is required to make the real-time communication possible. As the data needs post-processing, it was not possible to directly transfer all data to BIM.

a) TLS 3 setting options

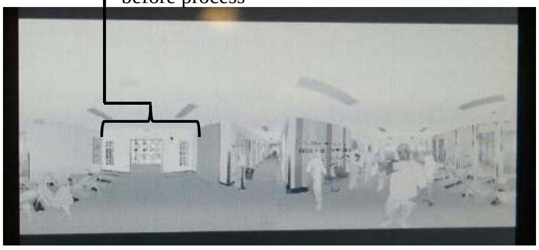


b) Setup point cloud resolution in TLS 3

c) Results can be demonstrated in TLS 2 before process



d) Required for using TLS 2



e) Results can be differently demonstrated in TLS 3 before process

Fig 2. Demonstration of settings and achieved 3D point cloud data using TLS

5. Development of Scanner Technology Acceptance Model

This section tends to develop a model based on the previous experimentations to predict the users' behaviors and intention in accepting a new scanner. Scanner technologies are different and more advanced comparing to conventional information technologies used in contractors head office. The scanner technologies provide accurate 3D data of the buildings and construction sites that can be used for energy exchange modelling, vegetation and building volume calculations and deriving geometrical characteristics of sustainability indicators. These major advantages of this technology lead us to seek out some measure to predict the users perceptions in terms of the scanner ease of use and usefulness. Since the extended technology acceptance models in information system disciplines cannot be applied directly in construction, a new extended model is required for predicting scanner acceptance in the construction industry.

5.1. Scanner Performance Expectancy

Performance Expectancy is defined as the degree to which a user believes that using the technology will help the user to gain in job performance [35]. The factor is a combination of several factors such as perceived usefulness, extrinsic motivation, job-fit, relative advantage, and outcome expectations. As this factor is known as an important factor in the literature, it is hypothesized that the performance expectancy influence the user behavioral intention to use the scanner, and it will be moderated by age, such that the effect will be stronger for younger and because their computer literacy might be more than last generation.

The experiments show that the process of integration Scanner 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 Scanner equipment enables us to use it in small and limited areas of complex buildings where adjusting terrestrial Scanner equipment is not possible. This is an important factor and other factors are related to this factor are discussed as follows:

Scanner job relevance (LJR) – The experiments show that all of these scanner technologies are applicable for updating design drawings and creating as-built drawings.

Scanner external control (LEC) – Another difference between the mobile and terrestrial Scanner is the external factor of cost. The cost of the mobile Scanner is three times cheaper than the multi-station scanner. At the same time, using mobile Scanner equipment does not need a skilled operator. However, processing the data collected by the mobile Scanner needs a skilled expert compared to the terrestrial Scanner which is fully commercialized.

5.2. Scanner Effort Expectancy

Effort expectancy refers to the degree of ease associated with the scanner implementation in the construction site. Two main constructs from the existing models embedded in the concept of effort expectancy: perceived ease of use, complexity. The results of the experimentations show how ease of use is the implementation of the advanced scanners in construction. Ease of use is one of the main advantages of a new information technology [32]. The implementation attributes including ease of use of a new technology are critical measurements of technology adoption in construction [23,25,29]. 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 related factors are discussed below:

Scanner result demonstrability (SRD) – All advanced TLS scanners and HMS scanners used in this study demonstrate the objects when an area is being scanned. However, the first hand held mobile scanner was not able to demonstrate the three dimensional object during scanning process, meaning that the operator would not get an understanding of whether or not the whole area is being scanned. But TLS shows the points that are being collected and the point clouds are saved and available for further analysis. Photogrammetric based hand held mobile device was sensitive to movements and when the device was moved very quickly, the scanner was not able to detect and create point clouds and a message appeared that the object had not been detected.

Scanner output quality (SOQ) – The results show that the terrestrial scanners are more accurate than mobile scanners in most cases, and from visual inspection terrestrial scanners provides high resolution point clouds than mobile scanners. 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 Scanner is more accurate than the mobile Scanner in most of the cases.

Scanner objective usability (SOU) – the data collection process of TLS is not as fast as HMS. The results of HMS also show that this type of scanner 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 [21]. 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 such as people and machineries. The experiments show using both mobile and terrestrial scanners can be more helpful for the shop drawers in order to create a mature model and easily update the documentation during construction.

5.3. Implementation Facilitating Support

Scanner Implementation Facilitating Support (IFS) refers to the degree to which a scanner user believes that a technical organisation such as a vendor exists to support the use of scanner. Some other factors in the literature such as perceived behavioural control, facilitating conditions and compatibility can be associated to IFS. The compatibility construct refers to the fit between the user's work style, and other current technologies and the use of the scanner in the construction company. So it is hypothesized that Scanner Implementation Facilitating Support will have a significant influence on both user behavioural and organisation intention.

5.4. User efficacy

Construction companies differ in believes about their competence and success in using technology for their construction operations. This cognition is called as "self-efficacy" at the organisational level and "collective efficacy" at the organisational level. Self-efficacy refers to believes in user's capabilities to use and operate a scanner and produce given attainments and required out puts. Collective efficacy refers to inquire about efficacy believes in organizations. It is a group referent perception and reflects an emergent organizational attribute known as perceived collective efficacy.

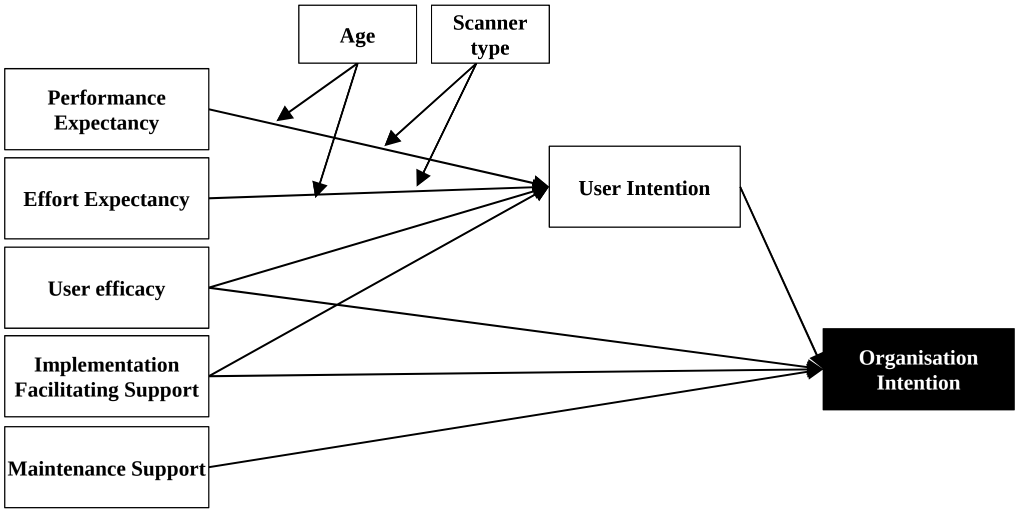


Fig 3. Schematic of Scanner Technology Acceptance Model (STAM)

Fig 3 depicts the scanner technology acceptance model (STAM) which is developed based on the above mentioned factors. The STAM is developed for predicting technology acceptance including five key factors. The model includes the cognitive instrumental processes such as performance expectancy, effort expectancy, user efficacy, implementation facilitating support and maintenance support. It proposes that the cognitive processes will have positive direct effects on user intention. The model is supported by previous experiments using experts' feedback. Table 1 provides a series of measurements for each factor. The factors have already been examined by the experts who were involved in the filed experiments [21,24,27,28]. However, a larger sample of participants will be helpful to examine the model and generalize the results. Future study would use the measurements to examine the factors in a larger scaled survey.

Table 1. Measures of key factors

Factors	Proposed measurements
Scanner performance expectancy	I would find the scanner useful for sustainability purposes.
	I would find the scanner useful for safety.
	Using the scanner enables me to accomplish my tasks more quickly.
	Using the scanner increases the productivity in our construction project.
	Using the scanner increases the performance in our construction project.
Effort expectancy	My interaction with the scanner would be clear and understandable.
	It would be easy for me to become skilful at using the scanner.
	I would find the scanner easy to use.
	Learning to operate the scanner is easy for me.
Implementation Facilitating Support	I have the resources necessary to use the scanner.
	I have the knowledge necessary to use the scanner.
	The scanner is not compatible with other digital devices I use.
	A specific person (or supplier) is available for assistance with scanner difficulties.
	My supplier provides proper training for scanner utilization.
	My company provides incentives if we accept using the scanner.
Maintenance Support	My vendor supports enough update resources (hardware and software) for scanner maintenance and compatibility with other updated technologies (e.g. software programs).
	My supplier provides spare parts and required services for scanner maintenance.
	My supplier is responsive for scanner maintenance.
Organisation self-efficacy	Me or someone else in my own company could complete a job using the scanner.
	If there was no one around to tell us what to do as we go.
	If we could call someone for help if we got stuck.
	If we had a lot of time to complete the job for which the software was provided.
	If we had just the built-in help facility for assistance.
	I have no difficulty telling others about the results of using the scanner.
	I believe I could communicate to others the consequences of using the scanner.
	The results of using the scanner are apparent to me.
	I would have difficulty explaining why using the scanner may or may not be Beneficial.
User efficacy	My organization does not have any resistance to using scanner.
	My organization is familiar to scanner technologies.
	My organization understands the benefits of using scanner technologies.
	I do not have any resistance to using scanner technologies.
	I am familiar with scanner technologies.
	I understand the benefits of using scanner technologies.

6. Concluding remarks

Scanners are known as an advanced tool for collecting data and potentially useful for assessing sustainability in construction. The current literature focuses on the feasibility of using a specific terrestrial scanner to acquire different types of data such as energy efficiency data for information modeling. However, it has not been explored how largely this potential affects the contractors' decision to use a scanner for their project. This paper aimed to develop a novel model to predict scanners technology adoption based on the field experiments. STAM modifies the generic technology acceptance model and specifies it for scanner technologies in construction. It provides a more detailed account of key influencers underlying the users' perceptions of ease of use and usefulness. The present study is based on field experiments and expert opinions. The results of using terrestrial (TLS) and mobile (HMS) laser scanners in the same test bed (an educational building at UNSW) were compared. The results of the field experimentations analyzed to identify influential factors in the implementation process. At the same time, theoretical acceptance model in the literature were reviewed and generic factors were identified. Based on the experiments and the systematic review, STAM is developed. This method gives a deep understanding of the technology implementation and assists in identifying the key factors in a systematic way. However, the identified factors which are based on STAM should be examined by a large scaled survey. The current research represents a very important contribution to the body of knowledge by modifying a generic model to address antecedents of key constructs: scanner performance expectancy, effort expectancy, organization self-efficacy, and user efficacy. In addition, based on the field experiments, two new constructs have been identified and addressed: implementation facilitating support, and maintenance support. Further research based on this investigation is to validate and enhance the model by larger scale consultation and interview process, and this will be reported in a future research paper.

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