Automated Data Collection for Progress Tracking Purposes: A Review of Related Techniques

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Abstract. The automated data collection of civil infrastructure projects, whether under construction, newly put into service, or in operation has been receiving increased attention by researchers and practitioners. Such real-time progress tracking is essential for the active monitoring of production during the construction phase of a project and for the built assets during their service lives. Automatic progress tracking can result in timely detection of potential time delays and construction discrepancies and directly supports project control decision-making. This paper outlines recent research efforts in this field and technological developments that aim to facilitate project management toward achieving project objectives. 3D imaging, geo-spatial, enhanced IT, and augmented reality technologies have recently achieved significant advances in this field. These technologies are discussed and compared herein in terms of their strengths and limitations to identify various trends concerning their applicability in data acquisition for construction projects and to formulate recommendations for their suitability in different projects. Prospects for improvement and challenges that can be expected in future research and development are considered. It is hoped that this discussion will assist construction stakeholders in choosing appropriate data collection tools, and motivate further research and development to assist in delivering projects on time and within budget.

Keywords: Construction industry · Automated data collection · Handheld IT tools · Geo-spatial · 3D · Sensing · Imaging

1 Introduction

Assuring proper delivery of civil infrastructure projects requires efficient and reliable performance control processes. The control process includes a forward information flow resulting from design, planning and management activities, and a feedback information flow for monitoring purposes to meet the overall expected project objectives (Turkan *et al.* 2012). Progress tracking is one of the most important feedback information types where the decision making, and consequently project success, undeniably depends on accurate and efficient progress tracking in the construction projects. However, it is sometimes difficult to adequately track and record changes during construction and hence could yield a final product that deviates from the

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as-designed state (Son *et al.* 2015). Therefore, and in order to avoid inefficient control processes, research efforts, driven by new technologies, have been directed toward the automation of data collection. Such development aims at rationalizing, streamlining and relating the data pertaining to a given project in order to extract valuable information in real-time (Bosche 2009).

For instance, 3D models could be generated to assess as-built conditions for construction monitoring purposes where 3D point clouds using either laser scanners or handheld digital cameras have been widely used for this purpose (Kim *et al.* 2013). Information technology (IT) tools have also been supported by a number of research studies to improve communication on construction sites and enable daily automated progress tracking of construction activities. The common applications include, but are not limited to, mobile computing, bar-code system, global positioning system (GPS), and radio frequency identification (RFID). In addition, the recent applications of augmented reality (AR) technology have helped in comparing as-built and as-planned statuses of construction projects during the construction phase and in monitoring project progress. Adopting such a variety of automated progress tracking technologies can enhance project control by providing different kinds of information such as construction standards, material transmission, vehicle locations, earth moving, and track of site activities (Tsai 2009), and thereby provide decision makers with timely progress details to follow the project progress more effectively, facilitating schedule updates and accurate schedule forensics, delay analysis, and planning of appropriate corrective actions. This paper provides a state-of-the-art review of mainstream studies on the automated data collection technologies and how they have been applied to address project tracking challenges.

2 Research Objectives and Methodology

The main goal of this study is to conduct a comprehensive literature review on the automated data collection technologies. To achieve this goal, the following objectives are pursued: (1) gain an understanding of the current state of the automated data collection research field; (2) investigate the potential applications of these technologies; (3) identify areas of concern associated with each technology; and (4) identify the knowledge gap for further research. Figure 1 illustrates the methodology adopted in the present research for the achievement of the above objectives as follows: (1) selecting the journals and articles; (2) reviewing the selected articles; (3) defining relevant

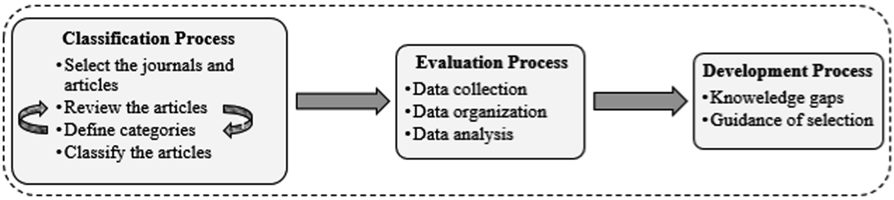

Fig. 1. The adopted research methodology for automated data collection technologies

categories; (4) classifying the articles in the defined categories; (5) evaluating the research progress in each category; (6) addressing challenges in the technology gaps that need further research and development; and (7) providing the bridge community with guidance for the selection of appropriate technologies.

3 Classification of Technologies

3.1 Selection of Journals and Articles

Eight diverse academic journals were adopted within the domain of project construction and management in an attempt to record the evolution of automated data collection technology in the architecture, engineering, construction, and facility management (AEC/FM) industry. Selection of these journals was based on their prominence in the research field of data acquisition to capture recent and relevant developments. Leading research conferences were also considered in a similar manner. The articles were searched using some key phrases such as "data acquisition" and "progress tracking". Articles such as calendars, editors' notes, subject indices, and content of volume were excluded in this phase.

3.2 Review the Selected Articles and Define Categories

The selection process initially identified more than 150 papers. The selected articles were examined in the second phase to extract their main findings and emphases. Articles that primarily focused on automation of data acquisition were discarded. The relevant literature was investigated from three perspectives, namely: (i) collecting as-built data; (ii) organizing as-built data: and (iii) analyzing as-built data. On the project process continuum of collecting, organizing and analyzing as-built data, and based on the various applications of the different technologies, four categories were defined and found to predominantly fit in the roles illustrated in Fig. 2. It is worth mentioning that reviewing the articles and defining the relevant categories were iterated until the final results were achieved. However, it should be also noted that there is a substantial overlap in the applications of the technologies regardless of their defined categories.

3.3 Classification of the Selected Articles in the Defined Categories

The articles were reviewed in this classification phase based on their principal focus and compared to the four defined categories. Qualitative and quantitative analyses were conducted based on the information gathered from each article. The quantitative analysis indicated that: (1) the Automation in Construction journal has the highest overall number of published data collection articles among the other journals; (2) the most frequent focus of the articles is on the construction phase; (3) infrastructure projects have the highest number of articles, whereas, residential projects have the least number of articles; (4) several articles had a principal focus on visualization, simulation

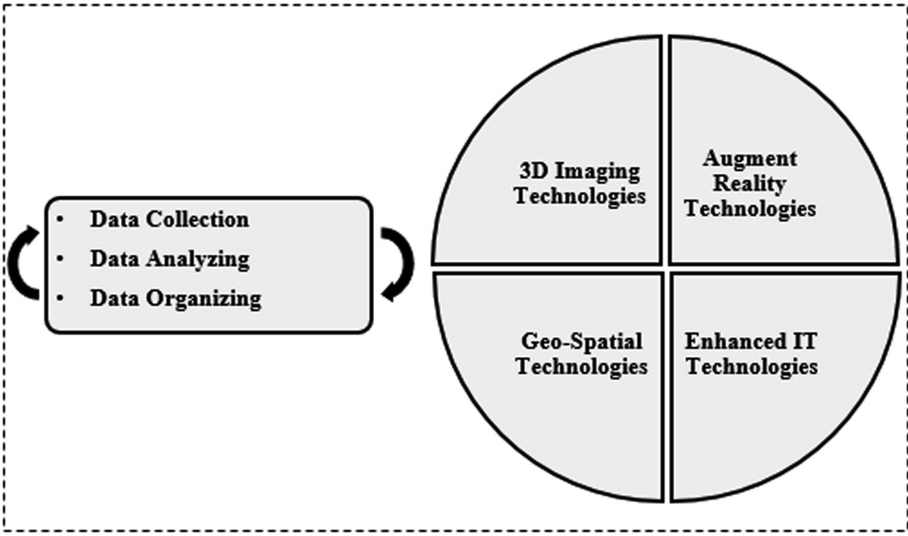

Fig. 2. Classification of construction progress tracking technologies

or communication; and (5) the majority of articles focus on the 3D modeling and the recent development and application of the AR technologies in the data collection field. The critical points of current knowledge in the field of data collection were considered. The research progress on each category was evaluated and presented in the next section and then investigated to frame its knowledge gaps.

4 Evaluation of Automated Data Collection Technologies

4.1 3D Imaging Technologies

Imaging technologies have been focusing on using digital images to generate 3D information about various objects on site for use in progress analysis. These technologies include, but are not limited to, photogrammetry, range images, videogrammetry and laser scanning. These methods differ in terms of capturing speed, cost, and processing time. For instance, the photogrammetry technology is an accurate technique to generate 3D models of a construction site from digital photos. The availability of inexpensive point-and-shoot and time-lapse cameras as well as smartphones has significantly increased the number of photos that are being captured on construction sites on a daily basis. Such an as-built 3D model is then compared to 3D CAD models to automatically calculate the percentage completion of each component and measure the progress of construction projects (Memon *et al.* 2005). Numerous researchers have applied photogrammetry for the automated collection of data. For example, Dai and Lu (2010) used photogrammetry to collect geometric measurements and orientations of building elements in order to record as-built information. El-Omari and Moselhi (2009) developed a tracking system that produces 3D images of scanned objects, which are then used to estimate quantities of work performed over the time interval between two scans. Ahmed *et al.* (2011) presented an efficient low-cost 3D automatic surveying method for pothole detection in pavements.

In addition, many photography documentation services, such as *EarthCam*, *MulitVista*, and *JobSiteVisitor,* have emerged in recent years to deliver "visual as-built" records of the construction phase to the project participant (Ahmed *et al.* 2011). Range images are a special class of digital images, also referred to as depth images. They are acquired with range sensors and offer an inexpensive and accurate means for digitizing the shape of 3D objects. 3D range cameras are useful for tracking moving objects and construction equipment and materials (Teizer *et al*. 2005). Teizer (2008) developed a 3D model using a high-frame range sensor to detect the characteristics of construction objects. Teizer *et al.* (2010) developed a method to rapidly determine blind spots using range images. Recently, a 3D range camera called *Kinect^TM^*, developed by *Microsoft*, has been used for safety purposes (Ray and Teizer 2012), performing real-time monitoring of construction workers to avoid hazardous postures and gestures. Range cameras are more expensive than digital cameras.

Videogrammetry technology has the capability to extract features from video recordings and hence, several studies have recently investigated the effectiveness and robustness of using videogrammetry in construction projects (Bosche *et al*. 2014). The level of accuracy for progressive reconstruction using videogrammetry has become reasonable using high resolution cameras. Dia *et al*. (2013) investigated two bridges and a building under different camera settings and reported that videogrammetry produced 3D point clouds without suffering from the site temperature changes or edge biases of the objects, but it was significantly impacted by a large number of factors such as the presence of robust features on the surface of the object, camera model, focal length, data capturing range, and the camera's resolution. However, similar to photogrammetry, videogrammetry can produce promising results, and thus needs concerted research efforts.

3D laser scanning has become a common technology to acquire 3D point clouds in many engineering fields. It was first introduced as an accurate method to capture construction sites and items and has been subsequently used to capture the current status of construction projects (Rebolj *et al.* 2008). Akinci *et al*. (2006) have shown that using 3D sensing and laser scanning technologies can avoid potential errors that cause rework. El-Omari and Moselhi (2009) compared some of the currently available 3D scanners in terms of speed, accuracy, range and cost. Gao *et al*. (2012) and Liu *et al*. (2012) utilized 3D laser scanning to capture actual construction progress and used the extracted information to develop a complete as-built BIM. Turkan *et al.* (2013) developed an automated object-oriented progress-tracking system to update the construction schedule through the use of a project 3D CAD model and 3D point clouds acquired via laser-scanning. However, Laser scanning is still not widely employed due to its high cost, need for a clear line of sight, and the difficulty of using it in congested interior work. Table 1 shows a brief comparison of some 3D imaging techniques.

Table 1. Comparison of 3D imaging techniques of data collection for progress tracking

Evaluation	Photogrammetry	Range images	Videogrammetry	Laser scanning
Affordability	High	Medium	Medium	Low
Portability	High	Medium	Medium	Medium
Processing time	Low	Medium	Low	High
Point cloud accuracy	Medium	Low	Medium	High
Range distance	Medium	Low	Low	High

4.2 Geospatial Technologies

Automated geospatial technologies are simple tracking tools to coordinate and share project data between personnel in the field and report progress updates to project stakeholders and managers. These technologies include, but are not limited to, barcoding, radio frequency identification (RFID), ultra-wide band (UWB) tags, geographic information systems (GIS), and global positioning systems (GPS). The barcode technology allows real-time data to be collected and has been proposed primarily for materials tracking, inventory, construction progress tracking and labour tracking (Navon and Sacks 2007), as well as for controlling engineering deliverables such as drawings, reports, and specifications (Shehab and Moselhi 2005), and for the management of documents (Shehab *et al.* 2009). It can be easily identified by mobile devices such as phones and is readable in any direction (Lin *et al.* 2014). The RFID system utilizes, by means of small tags, the radio frequencies to capture and transmit field data. Numerous researchers have applied RFID for the automated collection of data. For example, Ghanem and AbdelRazig (2006) applied an RFID wireless system for tracking construction progress. Song *et al.* (2006) used RFID for the automatic identification and tracking of individual pipe spools. RFID tags have also been widely used for tracking materials on construction sites. Montaser and Moselhi (2012) utilized RFID technology for tracking earthmoving operations in a near real time capturing system. While the RFID technology has a wide reading range and an ability to operate without line-of-sight (Song *et al*. 2006), it is associated with relatively high initial and maintenance costs (Ahmed *et al.* 2012).

The UWB is another type of radio technology that can be applied to short-range communications. Some potential applications of UWB technology on construction sites include material tracking and activity-based progress tracking as well as various safety-related applications (Shahi *et al.* 2012). For instance, Cheng *et al.* (2012) applied the UWB technology in construction projects where it was successfully used for a 3D material location tracking in real-time. Shahi *et al.* (2013) utilized the UWB positioning system to track the progress of pipeline construction activities (e.g. welding and inspection). The UWB technology has longer read ranges than laser scanning or vision-based detection and tracking systems and does not need to be integrated with other technologies to provide an accurate 3D location estimate (Shahi *et al.* 2012).

The Geographic Information System (GIS) have the potential of integrating project specific spatial and non-spatial information and has been widely utilized to analyze and manage large amounts of data involved in the procurement, preconstruction management, and construction monitoring (Petrov *et al.* 2015). Bansal and Pal (2009) presented a GIS based navigable 3D animation of project activities to visualise and review a construction project schedule as an alternative to existing 4D CAD tools. The animation of project activities utilises dynamic linkage between schedule activities and the corresponding 3D components, thus allowing detection of missing activities and logical errors in the project schedule. The database management capabilities of GIS are also utilised to maintain and update the construction resource database to facilitate project planning (Kang and Hong 2015). The Global Positioning System (GPS) is satellite-based and can locate the position of a specific object attached to a tag. GPS has been used for example to track steel structural materials throughout the construction process, from manufacturing to the construction site, from inventory until installation, and even for long-term maintenance (El-Omari and Moselhi 2011). Similar to GPS positioning, Shen *et al*. (2012) utilized a robotic total station and sensors to automate the process of data collection and positioning for a tunnel boring machine used in constructing sewer and storm water municipal pipelines. Table 2 shows a brief comparison of some geospatial techniques.

Table 2. Comparison of geospatial techniques of data collection for progress tracking

Evaluation	Barcodes	RFID	UWB	GIS/GPS
Storing information	Barcode labels	RFID tags	UWB tags	Geo-notes
Receiving stored information	Barcode readers	RFID readers	UWB readers	Signals
Modifying errors	Manual	Manual	Manual	Automatic
Transfer info within WLANs?	Yes	Yes	Yes	Yes
Require additional costs	No	Yes	Yes	Yes

4.3 Enhanced IT Technologies

Information technology (IT) - based communications are low-cost tools that have great potential to control project delays and cost overruns through improvement of communication (Liao and Tseng 2010). They include for example the multimedia tools (e.g. digital camera and video), email services, voice-based tools, short message services (SMS), and handheld computing tools. Multimedia tools are important because they enable information to be visualized and problem areas to be highlighted (Hegazy *et al.* 2008). For instance, Abudayyeh (2007) developed an information management model where a video camera and a microphone were attached for recording events related to activity progress. The proposed model linked the project schedule with the recorded timely multimedia field data. Abeid and Arditi (2002) developed *PHOTO-NET II*, a real-time monitoring system that links time-lapse images of construction activities with the critical path method (CPM) and progress control techniques. Leung *et al.* (2008) introduced a web-based collaboration platform that utilized network cameras to monitor the progress and quality of construction works in real-time and share the information with authenticated parties. Schexnayder *et al*. (2011) used a fixed webcam on a five-story building construction site to assist the construction management team in acting proactively, improving communication between site management and workers, and improving safety.

Elamin *et al.* (2009) used different criteria in evaluating project communication tools and categorized email as an effective technique to track, store, and extract progress data. Hegazy and Abdel-Monem (2012) proposed a low-cost framework that utilizes email to develop a project-wide system for progress tracking. The proposed framework integrates three main components: (i) email forms to collect as-built information; (ii) customized scheduling application to allow activities to be aware of their planned progress and automatically initiate communications to request updates on actual progress; and (iii) customized email tools that store the activities' communication parties. Based on the email responses of site personnel, the system automatically updates the schedule and generates an as-built full schedule report with all communications stored at the activity dates on a bar chart. Telephone systems can currently operate using a Voice over Internet Protocol (VoIP), or internet telephony. For example, Sunkpho *et al.* (2000) used voice commands to facilitate the documentation of bridge inspection through the use of handheld devices. Voice recognition was also utilized in construction by Tsai *et al.* (2007) as a means of recording and updating site material logs. Interactive voice response (IVR) has been used extensively by several companies for technical support purposes. It is an efficient tool that enables interaction with the user to automatically input site information into the system by voice and provides the ability to efficiently access information from computer systems (Schexnayder *et al*. 2011). Speech recognition and (IVR) systems can reduce the time and cost of collecting site information and record work progress (Jaselskis *et al.* 2011). Abdelrehim and Hegazy (2013) developed a voice-visual framework that integrates activity-specific tracking forms with different categories of site information and a cloud-based IVR service to communicate with multiple parties simultaneously with the calls dynamically controlled based on the user's answer.

Handheld computers and tablets are gaining popularity in the construction field and have been identified as important IT support for construction sites. They can enhance project control by providing site personnel with a variety of information such as resource data, project delivery information, and progress information (Ward *et al.* 2004). Smart phones and personal digital assistants (PDAs) can handle spreadsheet and industry-specific applications, and can have camera, GPS, voice, email, and internet access (Ghanem 2007). They could also be integrated with other technologies, such as barcodes and radio frequency identification readers. Tserng *et al.* (2005) attached PDA to barcode readers in order to support the management of supply and storage of materials on a construction site. Tablet PCs have been used for site information management to improve productivity by filling forms directly on site, while ensuring that construction quality standards are achieved (Ghanem 2007). Table 3 shows a brief comparison of some enhanced IT tools.

Table 3. Comparison of IT techniques of data collection for progress tracking

Evaluation	Multimedia	Email	IVR	Handheld computing
Portability	High	Medium	High	High
Processing time	High	Medium	Low	Medium
Associated cost	Medium	Low	Medium	High
Modifying errors	Medium	Medium	High	Medium
Ability of integration	Medium	Low	Medium	High

4.4 Augmented Reality

Augmented reality gives a view of the real world where elements are superimposed by computer generated files such as graphics, sounds, videos, or digital information. Although the application of augmented reality technologies in construction projects has tremendously increased in recent years, these technologies are still in the research stage and their full potential has not been fully achieved. The current AR application areas can be classified as visualization or simulation, communication or collaboration, information modeling, information access or evaluation, and safety or inspection (Shirazi and Behzadan 2015). It should be noted that the appropriate application areas for different types of AR will continue to evolve. AR has been used for instance in municipal infrastructure (Aschwanden *et al.* 2012), residential and commercial (Sampaio *et al.* 2012), highway (Golparvar-Fard *et al.* 2015), and industrial projects (Shin and Dunston 2008).

One of many specific applications of AR is the comparison of different project statuses. Reality versus model comparisons first involve the collection of site data through various means such as photogrammetry, videogrammetry (Brilakis *et al.* 2011), and laser scanning (Turkan *et al.* 2012). Then the collected data are compared with data provided within software models such as *4D BIM* (Golparvar-Fard *et al.* 2009). In order to make the comparison between as-built and model data intuitive, the two sets are usually overlaid. With the *4D BIM* model directly displayed with the as-built, decision-making personnel can identify construction progress statuses, any potential defects, and apply remedial actions if necessary. The current AR trend is the use of portable web-based mobile augmented systems for field construction monitoring (Wang *et al.* 2013). Examples of AR application that were successfully used for construction are *BIManywhere* and *SMART REALITY* where users focus on a given 2D printed paper

Table 4. Evaluation of augmented reality apps for progress tracking purposes

Criteria	Evaluation
Cost effective	Assuming the projects already have BIM and laser scanning capabilities, the apps are extremely affordable
Time and level of training required	Simple and easy for the end users in the field; and it enables all users to instantly access the information they need, saving precious time and avoiding frustrations with traditional systems
Level of automation	In order to deal with the intimidation posed by orienting in the BIM and laser scanner point clouds, AR automatically orients the user in the digital space and thus, covers the problem of navigation with 3D modeling
Level of readiness of required data	Data input is twofold; capturing the as-built environment at several stages during construction using 3D laser scanning and the creation of a 3D BIM
Capability to support the decision makers	The decision makers are able to walk into a room with a tablet and see exactly where everything is and access information on a piece of equipment without having to refer back to their computer

design or plan file with the camera on their iPad or iPhone. The apps then recognize the design. The screen overlays a virtual 3D model of what the structure will look like (Pena-Mora and Dwivedi 2002). Researchers are currently addressing practical challenges related to mobile field implementation of AR such as user comfort, power limitations, ability to function in harsh environments, robust image registration for outdoor uncontrolled conditions, filtering ambient noise and data interferences, and adding more interactivity features to the AR interface (Arashpour *et al.* 2015). Table 4 evaluates AR from the perspective of criteria found in the literature.

5 Challenges with Progress Tracking and Technology Gaps

Construction progress tracking is not a simple task and is associated with many challenges because construction projects involve large amounts of information related to a variety of functions, such as scheduling, construction methods, cost management, resources, quality control, and change order management. In addition, information is provided by a number of different sources and is presented in a wide variety of forms (Omar and Nehdi 2015). Furthermore, it may be difficult to track and record changes based on conscious decisions that are made during construction. It can even be more difficult to adequately track and record deviations that are more subtle and not emanating from conscious decisions (e.g., deviations due to poor workmanship) (Nahangi and Haas 2014). Most of the research efforts in the field of project control still focus on the development of cost control models where the earned value concept has proven to be the most reliable tool for tracking and control of construction projects (Xiong *et al.* 2013). More research is required to resolve knowledge gaps and better benefit the industry from adopting these technologies.

Recommendations for future research based on the analysis conducted in this study include: (1) resolving how to obtain complete sets of data as construction projects become larger and more complex. The problem of incomplete data will continue to significantly affect the automated measurement of construction progress; (2) solving how to automatically quantify the discrepancies between as-designed and as-built status; (3) providing the construction industry with cost analysis to help in the decision making process regarding the application of automated data acquisition technologies; (4) developing quantitative performance measures for tracking the progress of construction projects; (5) enhancing the integrated systems for automatically acquiring data for different construction areas; (6) integrating photogrammetry and laser-scan surveys with data acquired by other identification and localization technologies; (7) using 3D location sensing technology to develop mechanisms for tracking the movement of construction objects within construction sites; (8) enhancing methods which are based on scan-versus-BIM frameworks as they have not yet achieved a high level of effectiveness; (9) determining how BIM coupled with AR-based visualization can effectively interact with the information database provided on site to facilitate the physical context of each construction activity or task; and (10) improving the methods used for processing the huge amounts of 3D as-built data acquired from civil infrastructure projects that often have vast, noisy, and unstructured data.

6 Selection of Automated Data Collection Technologies

The present investigation of data collection technologies revealed that each technology has some advantages and can be employed in different applications during construction phases. For instance, IT techniques are powerful low-cost tools having great potential to control delays and cost overruns through improvements of project communication. However, numerous factors must be considered when IT approaches are applied in construction, such as the expenses of purchasing equipment and software, maintenance costs and upgrading of the hardware, the upgrading and licensing required for the software, the fees of required wireless services, need for in-house technical support personnel, and the training of users. Geospatial tools provide real-time data with a wide reading range and are considered high-durability tools in the construction environment. They also have the ability of tracking a material's progress through its supply chain, from manufacturing to the construction site gate. The data from geospatial technologies are becoming more effective and useful through their integration with other technologies such as 3D imaging, BIM and IT tools.

3D laser scanning can be used to track the progress of a construction site by recognizing existing built components and comparing them with the corresponding 3D CAD model. However, related commercial software packages are still too complicated for processing scanned data and the high equipment cost makes it unfeasible for small projects. In comparison, image technologies (photo/videogrammetry) are inexpensive, easy to use, and time efficient in acquiring data on site. The reduced level of accuracy compared to time-of-flight laser scanning constrains the applicability of image-based technology. Augmented Reality, in which 3D virtual objects are integrated in real time into a 3D real environment, is a promising technology that culminates numerous groups of technologies. The new AR software applications provide automated real-time notification systems and can record data that appear directly on the project schedule, and thus can provide timely schedule updates to help decision makers take better corrective actions. To identify key application areas that could be used to guide the construction industry and help the contractors to track and control their projects in a timely manner, the investigated technologies were compared from different viewpoints in Table 5.

Table 5. Comparison of available data collection technologies for progress tracking

Evaluation	3D imaging	Geospatial	Enhanced IT	Augmented reality
Applicability	All projects	All projects	All projects	All projects
Project size	Moderate/Large	Small/Moderate	Small/Moderate	Moderate/Large
Setup and cost	Very high	Medium	Medium	High
Automation level	Automated	Semi-automated	Manual	Automated
Training required	High	Low	Low	Medium
Pre-processing level	Medium	Low	Low	Low
Integrated readiness	High	Medium	Medium	High

7 Conclusions

Conventional construction progress tracking methods depend on extensive manual interaction, which is inaccurate, time-consuming, and labour-intensive even for small projects. Automated approaches have emerged as advantageous tools for quality management and as-built tracking purposes. This study presents an in-depth literature review of data collection technologies in the construction industry. For instance, 3D sensing technologies are the most accurate and speedy data collection tools that can be used for high precision purposes, so they are recommended for use in large, non-congested and accessible projects such as landmark development projects. Compared with some other locating technologies, RFID has its advantages in aspects of durability, rich data capacity, repetitive read/write, noncontact features, and low cost. It is also recommended for procurement management, preconstruction management, and resource management. Enhanced IT tools are relatively limited to tracking and documenting a project's status manually and hence are applicable mainly in small projects. AR applications are the most promising technologies, being suitable for all project types and sizes. They are growing rapidly as web-based and wireless network technologies are becoming more accessible.

The classification of the literature has enabled gaps in the automated data collection to be identified and future research directions to be proposed. Integrating these technologies alleviates limitations associated with each of them when employed individually. Many promising software applications have recently been used in the construction industry for data collection such as *Bridgit* as an IT enhanced tool, *iBeacon* as a geospatial tool, *Creaform Handyscan* as a handheld scanner, and *BIManywhere* as an augmented reality-based mobile app. However, it is worth mentioning that data collection technologies are evolving at an extraordinary speed and it is recommended to the construction participants to monitor this developing area closely in order to get the latest updates.

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