Responsible Design and Delivery of the Constructed Project
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INFORMATION MANAGEMENT TECHNOLOGIES FOR IMPROVING EARNED VALUE QUANTIFICATION

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Real-time progress tracking of construction activities is critical for successful project monitoring and control. As such, the application of modern information technologies for progress tracking are proclaimed to overcome the limitations of manual approaches and hence contribute to the automated acquisition of onsite data for the computation of the earned value of progressed work. To this end, this paper presents a thorough review of 111 studies dealing with automated data collection and progress tracking on construction sites. The researched technologies were classified into four categories, namely: information technology, geo-spatial, imaging, and augmented reality (AR). It was found that research dealing with progress tracking using imaging technologies has been speedily growing over the years. The findings also revealed that the highest frequency (57) of reported technologies is found to be related to the AR category, with 74 percent of these studies having been published in the last eight years. Moreover, 63 percent of the studies were concerned with all kinds of project activities, with more specific areas of application reported to include concrete and steel elements, MEP elements, indoor and outdoor elements. The encountered technologies are reported to decrease labor hours and the time needed for progress monitoring, and automated data collection on construction activities progress is said to facilitate the generation of status reports and permit the early detection of deviations from the as-planned status.

Keywords: Monitoring and control, Progress estimation, Project tracking, Data collection, Construction sites.

1 INTRODUCTION

Construction projects are nowadays more challenging in terms of time and budget constraints, thereby calling for devising better control and monitoring platforms (Chen *et al.* 2012). To this effect, and due to market pressure and global competition in the construction industry, a critical need for advanced management information systems had emerged. This need gave rise to the implementation of Earned Value Management (EVM) to limit projects' cost and duration overruns (Hunter *et al.* 2014). According to Naderpour and Mofid (2011), EVM is a recognized project management methodology that integrates cost, schedule, and scope into a unique measurement system, providing an early warning signal of project deviations from the plan, thus creating a chance to initiate timely corrective actions.

However, numerous researchers and practitioners have proclaimed that the main shortcoming associated with EVM is the difficulty in obtaining the percent complete of executed work. Ruskin (2004) considered "eyeball estimates" as personal and bias estimates of the percent complete of the executed works and are thus exposed to intended or unintentional biases.

Consequently, they are hard to repeat, and they may comprise huge errors (Ruskin 2004). Likewise, Humphreys and Visitacion (2009) assumed that using EVM as a standard practice may be an encumbrance, mainly since collecting significant data and information in construction sites needs a lot of effort by the project team. Moreover, Omar and Nehdi (2016) consider that construction progress tracking is not a simple task and involves challenges due to the large amounts of information in construction sites, mainly related to a diversity of functions, for instance, "scheduling, construction methods, cost management, resources, quality control, and change order management".

In recent years, construction information management has significantly benefited from developments in information and communications technology (ICT), by enhancing the speed of information flow and improving the effectiveness of information communication. As such, existing ICT has shown great potentials in enhancing on-site collection and retrieval of data (Chen and Kamara 2011).

2 SCOPE AND METHODOLOGY

The aim of this research is to explore the modern information management technologies reported in the current literature as contributing to the automated collection, retrieval, and transfer of on-site data for effective calculation of the earned value of executed works. The adopted methodology is as follows: (a) review the array of current research studies dealing with automated data collection and progress tracking; (b) cluster the various encountered technologies into general groups; and (c) address the benefits of applying those data acquisition technologies in construction sites. To this effect, a thorough in-depth review of the current literature dealing with data acquisition and progress tracking, published in the last two decades, has been carried out using online libraries and databases and based on the semantics and keywords-based methods. Many combinations of keywords, such as "data acquisition," "progress tracking", "automated data collection", "construction monitoring", "information technologies", and "progress measurement", were used to retrieve the relevant studies. The search resulted in filtering a set consisting of 111 relevant studies tackling the automation of data collection and progress tracking in construction sites, 62 percent of which were published over the last eight years. The adopted research studies were evaluated and categorized in relevant groups, allowing the identification of the main ICT areas proposed for use on construction sites for achieving more accurate earned value computations.

3 RESULTS AND ANALYSIS

3.1 Temporal Distribution of Research Studies

The 111 research studies were ordered and grouped according to their years of publication, as shown in Figure 1. It can be noticed that starting 2005 there seems to be a jump in the number of encountered studies, with the two middle ranges reflecting an average of seven publications per year. The last eight years (i.e., 2010-2017) encompassed a large number of publications (around 11 per year), showing the rapid evolvement of research tackling automated data acquisition technologies that have the potential to be used on construction sites.

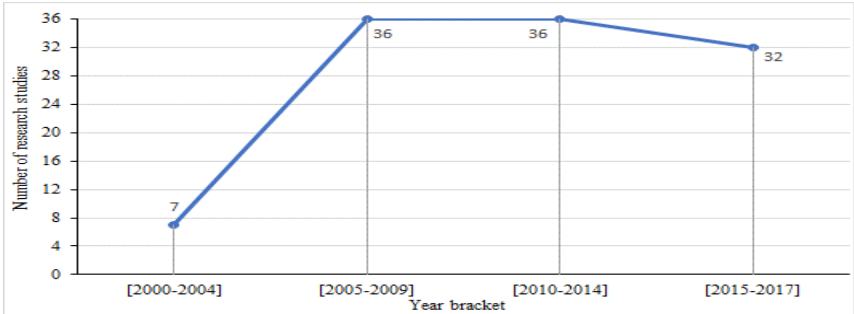

Figure 1. Temporal distribution of research studies.

3.2 General Screening and Findings

Figure 2 provides a general classification of the encountered relevant technologies for managing information on construction sites, classified according to four categories, mainly "enhanced IT", "geo-spatial", "imaging" and "augmented reality", following the classification of Omar and Nehdi (2016), along with the frequencies deduced in connection with each sub-class. To this effect, the various IT-based technologies included multimedia tools (digital camera and video) (Bohn and Teizer 2009), voice-based tools (Cheng *et al.* 2017), email and short message services (SMS) (Hegazy *et al.* 2014), and mobile computing tools (El-Omari and Moselhi 2011). Those inexpensive tools are said to enable the daily automated progress tracking of construction activities, leading to better schedule and cost control through enhanced communication.

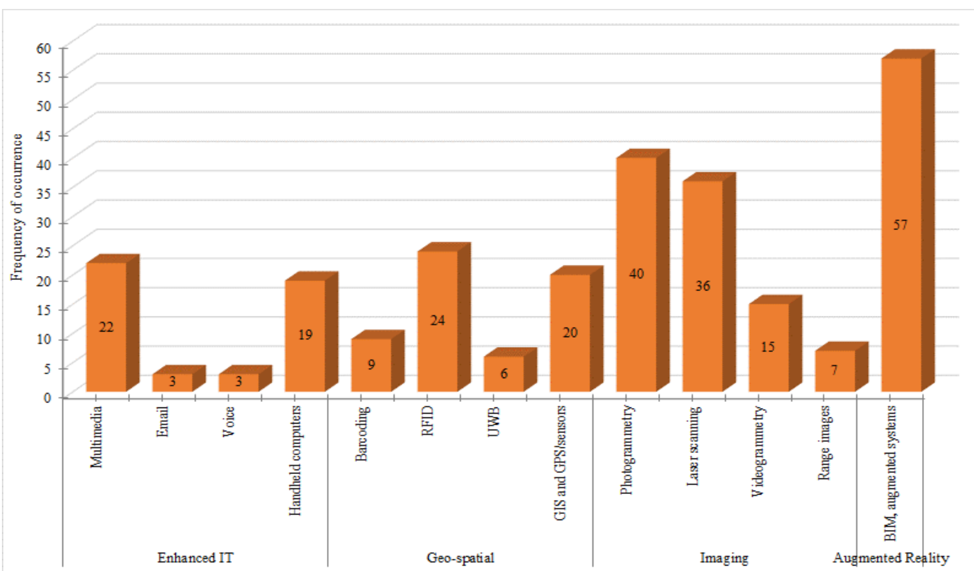

Figure 2. Frequencies of technologies for construction site data acquisition.

Moreover, Geo-spatial-based tools, including barcoding, radio frequency identification (RFID) (Khoury *et al.* 2015), ultra-wide band (UWB) tags (Shahi *et al.* 2014), geographic information systems (GIS) (Bansal and Pal 2009), and global positioning systems (GPS) (Behnam *et al.* 2016) are used to visualize on-site construction objects. Example applications include real-time 3D material, labor and equipment tracking. Furthermore, progress tracking based on imaging technologies has been focusing on using digital images to produce 3D information about various objects on a construction site in order to be used in project controls (Golparvar-Fard *et al.* 2011; Golparvar-Fard *et al.* 2012). Finally, augmented reality (AR), defined as "the combination of real and virtual scenes" (Wang *et al.* 2014), is mainly used for the comparison of different project status (Omar and Nehdi 2016). The most efficient AR application that is successively employed on construction sites is BIM (Han *et al.* 2017).

That being said, it can be noted that the highest frequency (i.e., 57) of reported technologies is found to be related to the AR applications group. This is explained by the fact that AR has a great potential to address a plethora of challenges throughout the project execution, by providing a "radical shift in human–computer interaction" (Omar and Nehdi 2016), thus receiving growing attention by researchers and industry practitioners. With an enduring technological evolvement of these applications, AR applications are progressively becoming more cost-effective with improved capabilities to deliver exhaustive data on various project activities. The evolvement of these data acquisition tools was further investigated, by providing the temporal distribution of the corresponding research work in the 111 reviewed studies. As shown in Figure 3, research on progress tracking using imaging technologies has been speedily growing over the years. Moreover, it can be seen that 42 of the 57 studies (74 percent) that employ AR applications for automated data collection were published in the last eight years (i.e., during 2010-2017). However, although work pertaining to AR technologies for construction projects has noticeably increased in the most recent years, as revealed in Figure 3, these applications are said to be still in the research phase and their complete capabilities have not yet been fully realized (Omar and Nehdi 2016).

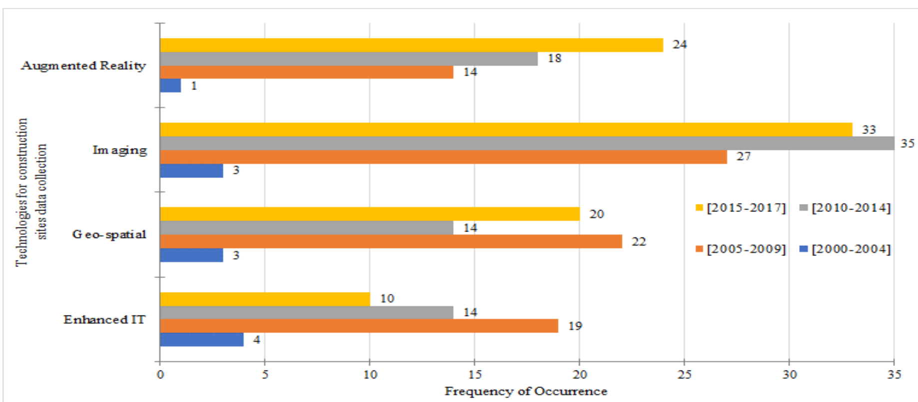

Figure 3. Temporal distribution of encountered technologies.

3.3 Areas of Application in Construction

A more detailed track of analysis tackled the significance of the above-mentioned findings from the perspective of the various areas of applications investigated as part of the reviewed published work. To this effect, Table 1 shows the breakdown of the filtered studies by the areas of application that were the subjects of investigation. It was found that 69 studies (63 percent) out of the examined studies (111, in total) were concerned with all kinds of project activities, whereas only one percent dealt with off-site construction activities. The more specific applications areas are found to include concrete and steel elements, MEP elements, indoor elements, and outdoor elements, among other similarly common on-site activities.

3.4 Benefits of Data Acquisition Technologies

Current methods for progress tracking on construction sites are mostly manual, labor-intensive, and time-consuming, and they are often based on abstruse and unreliable rules (Golparvar-Fard et *al.* 2011; Montaser and Moselhi 2015; Turkan *et al*. 2013). A considerable number of advanced automated data acquisition technologies, offering real-time on-site progress tracking, have been identified in this study. The encountered technologies are reported to significantly decrease labor hours and the time needed for progress monitoring. They allow this jobsite task to be achieved remotely and help in keeping track of the material used on construction site. It is found that real-time automated data collection on construction activities progress facilitates the generation of status reports and permits the early detection of deviations between the as-planned and current project statuses, thus allowing the timely flow of information between all interested parties. To this end, espousing such a variety of automated progress-tracking technologies can offer decision makers with prompt information in order to track the project progress more efficiently. The ultimate implication is the ability to produce accurate schedule updates and forensic delay analyses, and to better conceive suitable corrective measures.

Table 1. Distribution of technologies by areas of application in construction.

Specific application in construction	Number of research studies
General (any type)	69
Workers, materials and/or equipment	15
Infrastructure/Industrial	7
Concrete elements	6
MEP elements (cylindrical pipes and pipes spools)	3
Indoor elements	3
Structural steel elements	2
Earthwork	2
Outdoor elements	2
Secondary and temporary elements	1
Off-site construction elements	1

4 CONCLUSION

This study presents a literature review of data collection technologies that are used on construction sites for progress tracking and control. The analysis presented descriptions and classification of the emerging technologies, reported to be critical to effective data collection and retrieval. The paper highlights the usefulness of these applications in terms of increasing the efficiency of the tracking and progress reporting processes with less work done and fewer assumptions taken, with the aim of early detection of deviations between the planned and actual project statuses, thereby helping decision makers to take prompt corrective measures. Undeniably, the main obstacles for adopting the proposed technologies in construction include the excessive cost of procurement and maintenance of those emerging technologies, the necessity for extensive users training and the complexity of integration of these technologies with current applications. Data acquisition technologies that have the potential to be used on construction sites are hastily developing. Thus, it is highly suggested that decision makers carefully research their availability in order to get the up-to-date applications serving the purpose of achieving better monitoring and control of construction progress.

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