Abstract

Purpose – The purpose of this paper is to facilitate the process of monitoring construction projects. Classic practice for construction progress tracking relies on paper reports, which entails a serious amount of manual data collection as well as the effort of imagining the actual progress from the paperwork.

Design/methodology/approach – This paper presents a new methodology for monitoring construction progress using smartphones. This is done by proposing a new system consisting of a newly-developed application named “BIM-U” and a mobile augmented reality (AR) channel named “BIM-Phase”. “BIM-U” is an Android application that allows the end-user to update the progress of activities onsite. These data are used to update the project’s 4D model enhanced with different cost parameters such as earned value, actual cost and planned value. The “BIM-Phase” application is a mobile AR channel that is used during construction phase through implementing a 4D “as-planned” phased model integrated with an augmented video showing real or planned progress.

Findings – The results from the project are then analysed and assessed to anticipate the potential of these and similar techniques for tracking time and cost on construction projects.

Originality/value – The proposed system through “BIM-U” and “BIM Phase” exploits the potential of mobile applications and AR in construction through the use of handheld mobile devices to offer new possibilities for measuring and monitoring work progress using building information modelling.

Keywords Augmented reality, Building information modelling, 4D BIM model, Construction projects tracking, Hand-held mobile devices

Paper type Research paper

Introduction

Currently, handheld mobile devices are being used for a wide variety of applications. In the construction context, this includes augmented reality (AR), and the portability and accessibility of handheld mobile devices have prompted researchers to investigate their potential for automating construction site monitoring.

At the same time, the benefits of the use of building information modelling (BIM) – with coordinated and consistent views and representation of the 3D model including reliable “4D” (time) and “5D” (cost) data, for the design, construction and operation of built assets – have been widely publicised. Among these benefits, several relate to the potential for improvement in the productivity of onsite operations. In particular, according to Kim et al. (2013), this includes project tracking abilities and the ability to facilitate interactions and share information among project participants in real-time.
Effective progress tracking relies on periodic reports, which traditionally require manual data collection and entail frequent transcription (Turkan et al., 2012). Recent researchers have demonstrated how the mixing of virtual information with the real environment can be more efficient and effective in this respect. Golparvar-Fard (2006) reported that most project meetings are spent explaining and describing the rationale behind the decision-making process and less frequently involve value-adding tasks, such as evaluating and predicting the effects of a decision on the project. Moreover, low effectiveness rates on these decision-making tasks are reported. The process of understanding drawings, documents, specifications, etc., that take place during the project’s lifecycle often results in defects in design and rework in construction. The objective of this paper is to investigate the automation of the progress-tracking and subsequent data collection processes on construction projects. As such, this paper focuses on the exploitation of handheld mobile devices through explaining the development of new applications for tracking construction using BIM and AR. The proposed applications are demonstrated on a real construction project.

Research design
This paper is an example of inductive research that started with observations from current practice. This research aimed to explore the advantages of using handheld mobile devices on construction projects through integration of BIM and AR in a comprehensive system that allows users to monitor, update and visualise construction time and cost performance.

The research hypothesis is that handheld mobile devices, when combined with other technologies provide a powerful system for construction progress monitoring using BIM. Iyer and Jha (2005) considered progress monitoring to be an important factor for delivering construction projects on time and within budget. As a step towards improving construction progress monitoring on site, a system is proposed that allows project management to detect the performance deviations, which will in turn support their decision-making. The hypothesis is tested by building, testing and reviewing the proposed system of the featured applications on a real construction project using qualitative feedback from interviews. A semi-structured interview format was used to gain richer information about participants’ thoughts and opinions.

Paper structure
This paper has seven sections. In this introductory section, the problem is described, the research hypothesis defined and the research methodology outlined. The second section presents a review of BIM, AR, acquisition of construction data, and related work. The third section demonstrates the technical implementation of the featured mobile applications showing all the key applications used. The fourth section depicts the data flow within the developed applications. The fifth section presents the prototype and the interviewee reactions to the proposed system. The sixth section identifies the applications’ potential, implications and possible leverages that come from and its practical relevance. Finally, the last section evaluates the system through interviews and address issues that remain to be addressed in future work.

Literature review
Building information modelling
BIM has become well-known in the construction industry. The BIM is a three-dimensional digital representation of a building and its intrinsic characteristics. It consists of intelligent building components that can include data attributes and parametric rules for each object
BIM has attracted global attention in architecture, engineering, construction and facilities management (AEC/FM), as there is growing evidence that adopting BIM increases efficiency and productivity.

BIM construction management and scheduling tools are mainly used in clash detection, model and spatial coordination, and scheduling. Various examples of BIM tools that are available for these purposes are shown in Table I.

BIM usage and awareness is on the increase. In the UK, for example, according to the seventh NBS National BIM Report in 2017, from 2011 to 2017, the advance in BIM usage and awareness is demonstrated. Currently, 62 per cent are “aware and currently using BIM”, 35 per cent “aware but not using BIM” and only 3 per cent are “neither aware of nor using BIM” (NBS, 2017).

Augmented reality
AR is a technology whereby real and live images can co-exist with virtual information through the medium of a mobile interface (Zhou et al., 2008). This technology has been most commonly applied in the area of entertainment, retail, travel, advertising and social communication (Wang et al., 2013). Its increased ease of use and affordability has made the application of AR in the construction industry more feasible. At the same time, the potential for these tools for increasing efficiency and productivity has proved attractive to the AEC/FM sector (Golparvar-Fard et al., 2011).

Recent AR applications use different tracking configurations that can be classified into “marker-based” and “marker-less” types. Marker-based tracking is used for tracking a marker that mobile cameras can detect reliably. Moreover, the design of markers can usually ensure fast alignment to allow efficient tracking. On the other hand, marker-less tracking configurations can configure and track different targets without any markers. Marker-less tracking configurations allow the use of global positioning system (GPS), orientation, face/image detection, 3D maps and so forth. This research adopts the ID markers tracking

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Table I.
Examples of BIM tools for construction management
configuration as it can be used in outdoor and indoor environments. ID markers are 2D markers with a black border that can be reliably detected in simple applications.

Data acquisition of construction projects
In the USA, a 2012 survey revealed that 93 per cent of general contractors and 87 per cent of subcontractors sampled were using mobile devices on their job sites to increase productivity (Bernstein and Russo, 2012): such uses ranging from the more obvious (such as cameras) to the more technologically advanced, such as sensing devices and GPS. The range of potential site uses for smartphones has been explored by Kim et al. (2013).

Typical practice for progress tracking depends on supervisors’ daily or weekly reports, which involve intensive manual data collection and entail frequent transcription or data entry errors. Field engineers and/or superintendents rely on 2D as-planned drawings, project specifications and construction details to review the progress achieved by that date then study these reports. After that, they study the construction schedule to identify the work planned to be done by that date. This requires a significant amount of manual work that may affect the quality of the progress estimations (Kiziltas and Akinci, 2005).

To overcome such limitations, commercial applications have been developed for improving construction monitoring and recording project progress on the site. An example is “Site Progress”, which is only designed to work with a database created using the Asta Powerproject software. However, Asta Powerproject does enable users to open and save in various other formats – including Microsoft Project and Primavera (elecosoft, 2017).

Related work
The present section concentrates on the AR applications in the field of AEC/FM that have been developed in previous research, some of which are computer-based. Examples of distinctive AR/BIM applications that have already been developed include BIM2MAR (Williams et al., 2015), (Zollmann et al., 2014), HD4AR (Bae et al., 2013), AR4BC (Woodward and Hakkarainen, 2011) (Woodward et al., 2010) and D4AR (Golparvar-Fard et al., 2009).

Williams et al. (2015) developed an application called BIM2AR and conducted a pilot study of facility management at the Shepherd Centre in Atlanta, GA, in a health-care facility management context. One of the main focus areas for this project was to determine a method to provide complex geometry on a computationally simplified mobile platform. BIM2AR was implemented through using Argon 2 (an AR browser that is under development), Vuforia for vision-based tracking and Metaio for model-based tracking. Facility managers who use this application should stand in a predefined location in the room for the 3D geometry to be registered accurately with real environment in a real-time.

Zollmann et al. (2014) introduced an approach for using AR for construction site monitoring. The authors developed methods for 3D reconstruction and aerial data capturing. Through the availability of data and usage of additional sensors such as GPS and IMU or purely vision-based, the authors offered progress visualisation directly on the site.

HD4AR was implemented for mobile usage by using the image feature point as the basis for user localisation and a “Structure From Motion” (SFM) algorithm to build and match a 3D geometric model using regular smartphone cameras. HD4AR can develop a near real-time AR using images, taking 3-6 seconds for localisation and less than 1 hour for point cloud generation (Bae et al., 2013).

The A4BC application was implemented for mobile visualisation in various modes and along the timeline, masking the virtual model with real images through GPS. Woodward and Hakkarainen (2011) presented their work on AR4BC software based on laptops, tablets and mobile phones, and using 4D Studio, MapStudio and OnSitePlayer. The 4D studio
module was used to read-in building information models and link them to a project time schedule. The MapStudio module is used to position the building model on a map using geographic coordinates, while the OnSitePlayer module is the mobile application used to visualise the model data on top of the real worldview using AR. The authors used two “marker-less” methods for tracking as explained below. The first method was GPS, but this is not a good tracker for indoor environments. The second tracking method was by obtaining actual 3D coordinates of the tracked feature which were obtained by initializing the camera pose and rendering the depth map of objects.

The D4AR system was implemented in Microsoft C++ .Net using Microsoft DirectX9 graphics library for computers that were used for visualising the deviation of progress through registering new daily site images and using a traffic light metaphor. Preliminary results have been presented based on three ongoing construction projects. However, there are technical challenges in developing an automated construction progress tracking system.

**Technical implementation of the proposed system**

The proposed system is advanced through developing a “BIM-U” android application and a “BIM-Phase” channel that can be viewed on Android and IOS as well. “BIM-U” and “BIM-Phase” complement each other, as these applications update work progress, visualise actual progress and compare it with the planned model (Figure 1).

The proposed applications were developed using a combination of tools and constituents, as follows:

- *Primavera P6 R8.3*: This application is used to develop time schedules using CPM (Critical Path Method) method assigned with resources.
- *Autodesk Revit*: This application is used to develop BIM models.
- *Autodesk Navisworks*: This application is used for integrating the 3D model with a resource-loaded time schedule to develop the 5D simulation in the project in various stages.

![Considered Applications](image)

**Figure 1.** Relation between the considered applications

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• **Fusion tables**: This is a data management Web-based service provided by Google that allows data collection, sharing and visualisation, including Microsoft Excel connected with Google drive. This is used here for updating the activities’ actual start, finish, duration, cost, and performance in familiar, spreadsheet-like rows and columns.

• **MIT App Inventor**: App Inventor is an open-source cloud-based tool that can build Android apps through a web browser using the Java programming language. This tool is divided into a group of blocks that have functions and a design interface that facilitates end-user operation. (MIT, 2017)

• **Metaio Creator**: Metaio Creator is a tool that allows the creation and deployment of AR scenarios.

• **Junaio**: This mobile application is used to create AR channels. Junaio creates channels that support location-based services, QR-Code, barcode and ID marker detection and 2D image tracking.

A large number of AR development tools are available. Table II lists a sample of the effective AR tools that can be used in AEC/FM industry. Some of these tools work on mobile-handheld devices and others on PC and webcam using different tracking configurations. In this research, the products of the software producer Metaio (Metaio Creator and Junaio) were used extensively. Following Apple’s purchase of Metaio in May 2015 one of the products Metaio Creator, is no longer available (Miller and Constine, 2015). However, a range of substitute applications, listed in Table II, are available for the different aspects of AR for construction that are considered in this paper.

The architecture of the developed Android application “BIM-U” requires the integration of all data through one application. The integration process takes place in the MIT App Inventor tool as shown in Figure 2.

Figure 3 illustrates the different applications that constitute the proposed AR framework combining the functionalities of the different applications that can be viewed on the Junaio AR browser.

**The “BIM-U” application**

BIM-U is an Android application that is superior to other commercial applications because the retrieved data can be used via an Excel spreadsheet to any other scheduling application such as Microsoft Project and Primavera. BIM-U has been developed using MIT App Inventor, a brief description of which was given above. For setting-up the live testing of the built application before launching, MIT App Inventor (MIT, 2017) offers three different approaches to developing and debugging. If the Android device is being used with an internet connection, the

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Table II. Augmented reality (AR) tools
relevant apps can be run without downloading any software to the computer. For viewing the designed application on the device, MIT App Inventor Companion is recommended. If an Android device is not available, then software needs to be installed on the computer to allow the use of on-screen Android emulator. Finally, if a wireless internet connection is unavailable, special software is required to be installed on the computer so that a connection can be established to the Android device through a USB connection. Figure 4 depicts an example for developing a login screen using the blocks function.

As the data extracted from the application is used for updating the model, the 4D/5D model visualises the difference between the planned and the actual progress of the project as detailed below. The updating process is accessed after entering the username and password of the user to grant access only to the users who have the log-in password to start updating through fusion tables.
Internet development has made cloud computing more appropriate for use as an information platform. The potential of a cloud computing-based service has been extended to various uses in construction management applications. Chi et al. (2013) defined cloud computing-based services as the service provided over the internet, the software data servers and the hardware that provides these services. This research uses Google Fusion tables as a Platform as a Service (PaaS) to store information and update time schedule over the internet.

Effective tracking of site activities and retrieval of project information requires a user-friendly interface for the developed Android application. The developed Android application start screen shows the options available to the end-users. Figure 5 depicts a screenshot of the fusion table that is connected with the developed Android application to collect the update which the update can be readily transferred over the internet using the cloud computing-based service using the fusion tables which is connected to the Android mobile application to gain the benefits of the accessibility and portability of mobile devices. This fusion table is connected to “BIM-U” through an application programming interface (API) key. Programming blocks are developed and validated to ensure correct working. The connection between the fusion table and the Android application takes place through an API key.

The “BIM-Phase” application
The 4D/5D model is the core of the “BIM-Phase” channel application. A 3D model was developed for an administrative building using Autodesk Revit and integrated with time schedule prepared with Primavera R8.3 associated with the concrete budgeted cost for further controlling. This integration took place through Navisworks, which is used to export
the 4D model in .avi extension to be integrated with cost parameters as an augmented video through Metaio Creator. The 4D/5D model can be periodically updated through the BIM-U application. As a preliminary step, a trackable ID marker is configured to be identified in the Metaio Creator (an ID marker was selected as the ideal “trackable” as it can be reliably and easily detected). Once a 5D video has been prepared using Navisworks and is ready to be assigned to the selected trackable, the project can be divided into phases to view the as-planned model. In the current research, the project was divided into six phases for each phase exported from the Revit model into different .dae models using the Collada interchange file format exporter. Collada exporter is an add-in that permits the saving of 3D models in a format that Metaio Creator can directly read. As such, the phasing of the project and the 4D/5D model are assigned to an ID marker to be ready for Junaio channel generation to visualise an augmented 5D video and 3D model for the project’s phases.

Data flow within the featured applications

Before presenting the results of testing the efficacy of the featured applications in the field, a brief description of the proposed data flow is presented. The essential cost control process that is carried out during the execution of construction projects requires the calculation of such parameters as the budgeted cost of work scheduled which is also known as the planned value (PV), budgeted cost of work performed which is also known as earned value (EV) and actual cost of work performed (ACWP). The “BIM-U” application represents the difference between the aforementioned parameters through a 4D model and is thus used to visualise it in “BIM-Phase” to determine if the project is under/over budget and ahead of/behind schedule. This, in turn, assists construction managers in taking corrective actions, if any is required.

Returning to the BIM-U Android application, the information to be acquired includes “actual start”, “actual finish”, “progress percentage complete”, “WBS code” and the allocation of the activities responsibility to each engineer on site. Second, BIM-U transfers these results to Google Fusion tables, as described earlier (Figure 5). Third, the actual cost of each activity and the budgeted total cost can be updated offsite after exporting the updated results from the Android application onsite to a Microsoft Excel comma-separated value file (.CSV) through the Google Drive. Finally, the final results are synchronised through the previous update to be imported into Navisworks after scheduling. The BIM-U process is repeated as the data is collected and updated periodically. Figure 6 depicts BIM-U application tree that illustrates this data flow from the construction site to end-users. The application has three screens. The first screen contains the essential information such as project’s location, description, stakeholders, perspectives and the estimated cost of the project. The second screen opens the updated 4D/5D model that is uploaded over the internet, and which is updated periodically through the same application. The third screen is used for updating the time schedule as previously depicted in Figure 5.

Project information needs to be updated periodically to track the project’s status, and this process takes place through the BIM-U application as shown in Figure 7. The data entry process takes place both onsite (for capture) and offsite (where the actual cost of each activity can more readily be calculated).

To implement BIM-Phase, the applications pass through different phases. These phases are the data collection phase, the implementing phase and the AR browsing phase. In the data collection phase, all efforts are towards acquiring the essential data such as augmented videos, 3D models and documents with different applications; while, the implementing phase is for implementing the AR application using the acquired data to be ready for processing using Metaio Creator. Finally, three different channels for the applications are
generated on Metaio Creator to move to the visualising phase through Junaio mobile application. Figure 8 depicts the data flow in BIM-Phase AR application.

Every AR application implemented using Metaio Creator has a channel with a QR code to be opened on the AR browser. First, the user downloads Junaio mobile application from Google play or App store. Second, the user clicks on the scan button to scan the QR code. Finally, the AR implemented channel is viewed.

Prototype for testing the featured applications
To test site progress tracking through the BIM-U Android application, a real project was selected as a prototype. The project was the construction of an administrative building located in Smart Village, Giza, Egypt with a total building area of 13,000 m². The construction of the concrete skeleton had a planned duration of 65 weeks. BIM-U was tested to verify the usage of the developed Android application using a Sony Xperia C smartphone with a 5-inch TFT capacitive touchscreen and an 8-megapixel front camera with Quad-core 1.2 GHz Cortex-A7 processor. Mobile 3G/WCDMA networks were used to enable data transfer.
The input data updated in BIM-U are “activity name”, “performed progress percentage”, “actual start”, “actual finish” and “WBS code”. These data were used to update the existing time schedule in Primavera (e.g. with data date May 10, 2014) with actual progress (e.g. up to a data date of May 17, 2014). Thereafter, the updated time schedule was exported to Navisworks in .CSV format to synchronise it with additional data calculated using Primavera. These data are the PV, EV and the ACWP for the activities, as explained in an earlier section. As such, Navisworks was able to export the 4D/5D model for the current data date (e.g. May 17, 2014) for tracking the project progress, visualising the updated/planned 3D model and predicting the final total cost.

The 4D/5D model was exported as a video to be presented in BIM-U and BIM-Phase. These results were used to compute important parameters in cost control management to check project status with respect to time and cost such as cost performance index (CPI) and schedule performance index (SPI). The results show that the project has an over-run in terms of the project’s budget, and behind schedule as well (as the calculated CPI and SPI are 1.03 and 0.95, respectively), is indicating required recovery actions.

In BIM-Phase channel application after updating the 4D/5D model using BIM-U, the project is optimised to be phased into six phases. Each phase is executed in 10 weeks, except the last one which is executed in 15 weeks as the project’s duration is 65 weeks (Figure 9).

As shown in Figure 9, an ID marker is printed to be used as trackable to be used with BIM-Phase channel. BIM-Phase shows six buttons in the bottom of the screen numbered from 1 to 6 for the project’s different phases. The concrete skeleton is divided into six phases as above, where the user has the flexibility to change the phasing interval in the AR creator tool. When a button has tapped the model of each phase is rendered on the ID marker. In Figure 9, the rendered model represents the first phase. Moreover, behind the 3D model of the first phase, an augmented 4D/5D model visualises the planned progress of works in each week and day combined with the planned cost. As shown in the screenshot, there are six buttons offering visualisation of the as-planned 3D model in AR the adopting the project phases and visualising an augment video showing the actual progress that is updated from
“BIM-U” or the planned progress as previously developed in the AR creator, where different colours were allocated to the various activities: the process of fixing the steel reinforcement for columns and slab was represented in red, shuttering for columns and slab in yellow, and the model takes its final appearance at the end of the concrete pouring activity (Figure 9).

The system’s effectiveness was evaluated through semi-structured interviews with architects, planning engineers, cost control engineers and site engineers. Individuals were chosen on a “network selection” basis. The semi-structured interview was selected to identify several key questions as compared to structured interviews it is considered to be more flexible. The interview started with an introduction to the work. The key questions were:

Q1. To what extent do you believe that AR has potentials in the construction management field?
Q2. How can AR assist in tracking construction projects?
Q3. Do you have any ideas for enhancing the presented work?
Q4. Who should be recommended to use the presented work?

Generally, the participants confirmed the potential of AR in the construction industry as it is user-friendly, and it is a tool that could be used for simplifying/visualising complex data set in the field. Also, AR allows improved collaboration between project stakeholders. Workers
can visualise site instructions, required materials and workflow using AR. With regard to the present work, the feedback received was that the system under consideration may:

- reduce the time of explaining information;
- reduce the time of construction;
- decrease errors compared with updating using paperwork; and
- increase the satisfaction of the project’s stakeholders through the facilitation in visualising information, which increases the effectiveness of decision-making.

On the other hand, it was recommended to:

- integrate the whole system in one application;
- improve the rendered model of “BIM-Phase channel”; and
- address the time gap that could occur between updating the time schedule and “BIM-Phase channel”.

It is recognised that there is a considerable amount of work that would need to be done prior to implementing the system. This work can be summarised in developing a BIM 3D model, time schedule, integrating cost model and collecting data. It is likely, however, that projects of a significant size will already have the 3D model which is the most time-consuming task.

**Conclusion and future work**

In this article, the starting hypothesis was that handheld mobile devices, when combined with other technologies, such as AR, and using BIM, provide a powerful system for construction progress monitoring. We proposed a system that allows enhanced project control through visualisation of construction progress directly on-site, using AR. The most stringent problems in the construction industry are related to time, cost and quality. The use of BIM alongside handheld mobile devices such as smartphones and tablets has the potential to address these problems. A great deal of research has already used AR on AEC/FM projects, and examples have been presented. However, the current work presents a different technique of using a 4D/5D AR application.

What sets this work apart from others and provides it with a distinctive edge for construction projects is the concept of using a mobile application for updating progress through cloud computing-based services using PaaS (i.e. fusion tables). This enables users to update progress from different areas in the project using mobile devices regardless of the scheduling tool used. This solves the issue raised by Zollmann et al. (2014) that AR does not allow for visualisation of as-planned structure. “BIM-Phase” solves this issue by allowing visualisation of as-planned structure through phasing along with a 4D/5D augmented video that provides different cost parameter tools to manage projects more effectively.

This research has proposed a system with an Android application named “BIM-U” and an AR channel named “BIM-Phase” that, if adopted, could have considerable leverage in the construction industry. The architecture of designing and implementing the applications was explained. These applications have different designated functions. The first, BIM-U, is used for progress tracking and 5D modelling for planned and actual progress. The second, BIM-Phase is used for the planning and cost control perspective and operates by mixing virtual information with the real environment and visualising a 4D/5D model during construction with its essential cost parameters for more effective monitoring. These parameters are used to compute time and cost, in the form of a CPI and a SPI. An experimental case study was carried out on an actual project, to test the applications. In the example given, the project
showed an under-run against its estimated budget but was behind schedule (as the calculated CPI and SPI cost parameters were 1.03 and 0.95, respectively). The resulting data flows were as designed and produced results that indicated the efficacy of the concept and the design of the system. The nature of the semi-structured interview approach allows ideas to emerge that had not previously been envisaged by the research team. The new ideas generated by this study that will be addressed in further work. These include: visualising planned structure on the physical environment to figure out deviations between the actual progress and planned model. Additionally, there is the matter of improving the proposed system in the form of using more effective hardware (such as HoloLens) and by then conducting user studies. These may be qualitative, taking the form of collecting user reactions to the applications, or possibly quantitative, in terms of measuring the accuracy or efficiency gains of the new system.

References


**Corresponding author**
Mohamed Marzouk can be contacted at: mmm_marzouk@yahoo.com

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