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Mobile Augmented Reality Applications for Construction Projects

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Mobile Augmented Reality Applications for Construction Projects

Abstract

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. This data is 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 utilised during construction phase through implementing a 4D 'as-planned' phased model integrated with an augmented video showing real or planned progress.

Purpose

Current researchers have attempted 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.

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 Augmented Reality (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:

Building Information Modelling, Augmented Reality, Handheld mobile devices, Construction Project Tracking, Progress Monitoring.

Introduction

Currently, handheld mobile devices are being used for a wide variety different applications. In the construction context, this includes Augmented Reality, 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 et al. (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 utilising 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 (2015) 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 in order 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. Section two presents a review of BIM, AR, acquisition of construction data, and related work. Section three demonstrates the technical implementation of the featured mobile applications showing all the key applications used. Section four depicts the data flow within the developed applications. In Section five the prototype and the interviewee reactions to the proposed system are presented. Section six identifies the applications' potential, implications and possible leverages that come from and its practical relevance. Finally, section seven evaluates the system through interviews and address issues that remain to be addressed in future work.

Literature Review

Building Information Modelling

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 (Hergunsel, 2011). BIM has attracted global attention in Architecture, Engineering, Construction and Facilities Management (AEC/FM) since 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 1.

Insert Table 1

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% are 'aware and currently using BIM', 35% 'aware but not using BIM', and only 3% are neither aware of nor using BIM' (NBS, 2017).

Augmented Reality

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 Architectural, Engineering, Construction, and Facility Management (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 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% of the general contractors and 87% of subcontractors sampled were using mobile devices on their job sites to increase productivity (Bernstein & 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. (2103).

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 amounts of manual work that may affect the quality of the progress estimations (Kiziltas & 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 workThe 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 & 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, Georgia, in a healthcare 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 utilisation 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 augmented reality using images, taking 3-6 seconds for localisation and less than one 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 the Global Positioning System (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, whilst 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 (see Figure 1).

Insert 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.
- 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 2 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 & Constine, 2015). However, a range of substitute applications, listed in Table 2, are available for the different aspects of augmented reality for construction that are considered in this paper.

Insert Table 2

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.

Insert 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.

Insert Figure 3

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 relevant apps can be run without downloading any software to the computer. For viewing the designed application on the device, App Inventor Companion App 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.

Insert Figure 4

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 PaaS (Platform as a Service) 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 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 application programming interface key (API).

Insert Figure 5

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 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 (BCWS) which is also known as the Planned Value (PV), Budgeted Cost of Work Performed (BCWP) 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. Secondly, BIM-U transfers these results to Google Fusion tables, as described earlier (see Figure 5). Thirdly, 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. Lastly, 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.

Insert Figure 6

Projects information needs to be updated periodically to track the projects' 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).

Insert Figure 7

In order to implement BIM-Phase, the applications pass through different phases. These phases are (1) Data collection phase, (2) Implementing phase, and (3) 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. Whilst, 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.

Insert Figure 8

Every AR application implemented using Metaio Creator has a channel with a QR code to be opened on the AR browser. Firstly, the user downloads Junaio mobile application from Google play or App store. Secondly, 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

In order 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 Planned Value, Earned Value, and the Actual Cost of Work Performed 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) indicating any 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 (see figure 9).

As shown in Figure 9, an ID marker is printed to be used as trackable in order 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 projects' 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 Augmented Reality 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 1) visualisation of the as planned 3D model in AR the adopting the project phases and 2) 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 (see Figure 9)

Insert 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 compared to structured interviews it is considered as more flexible. The interview started with an introduction to the work. The key questions were 1) To what extent do you believe that AR has potentials in the construction management field? 2) How can AR assist in tracking construction projects? 3) Do you have any ideas for enhancing the presented work? 4) Who should be recommended to use the presented work? Generally, the participants confirmed the potential of AR in the construction industry as it 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: 1) reduce the time of explaining information, 2) reduce the time of construction, 3) decrease errors compared with updating using paperwork, and 3) 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 1) integrate the whole system in one application, 2) improve the rendered model of 'BIM-Phase channel', and 3) 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 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 utilised AR on Architectural, Engineering, Construction, and Facility Management (AEC/FM) projects, and examples have been presented. However, the current work presents a different technique of using the 5D in Augmented Reality.

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 that is adopting an Android application named 'BIM-U' and an AR channel named 'BIM-Phase' that, if adopted, couldhave 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 Cost Performance Index (CPI) and a Schedule Performance Index (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.

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Table 1: Examples of BIM tools for construction management

Product Name	Developer	BIM Use	Developer Web Link
Navisworks Manage	Autodesk	1. Clash detection 2. Scheduling 3. Coordination	www.autodesk.com
ProjectWise Navigator	Bentley	1. Clash detection 2. Scheduling 3. Collaboration	www.bently.com
DP Manager	Digital Project	1. Scheduling 2. Model review 3. Collaboration 4. Quantity take-off	www.digitalproject3d.com
Visual 4D Simulation	Innovaya	1. Scheduling 2. Coordination	www.innovaya.com
Vico Office	Vico Software	1. Scheduling 2. Coordination 3. Cost estimation 4. Quantity take-off	www.vicosoftware.com
Solibri Model Checker	Solibri	1. Clash detection 2. Coordination 3. Quantity take-off 4. Design review	www.solibri.com

Table 2: Augmented Reality (AR) Tools

Product Name	Manufacturer	Supplier Web Link
Layar	Layar	https://www.layar.com/
Hyperspaces	AR-media	http://www.armedia.it/
Wikitude SDK	Wikitude	http://www.wikitude.com/
D'Fusion Studio	Total immersion	http://www.t-immersion.com/
ALVAR	VTT Technical Research Centre of Finland	http://virtual.vtt.fi/virtual/proj2/multimedia/index.html
maxReality	Vuzix	https://www.vuzix.eu/
ARToolKit	DAQRI ARTruth Co. Ltd.	http://artoolkit.org/

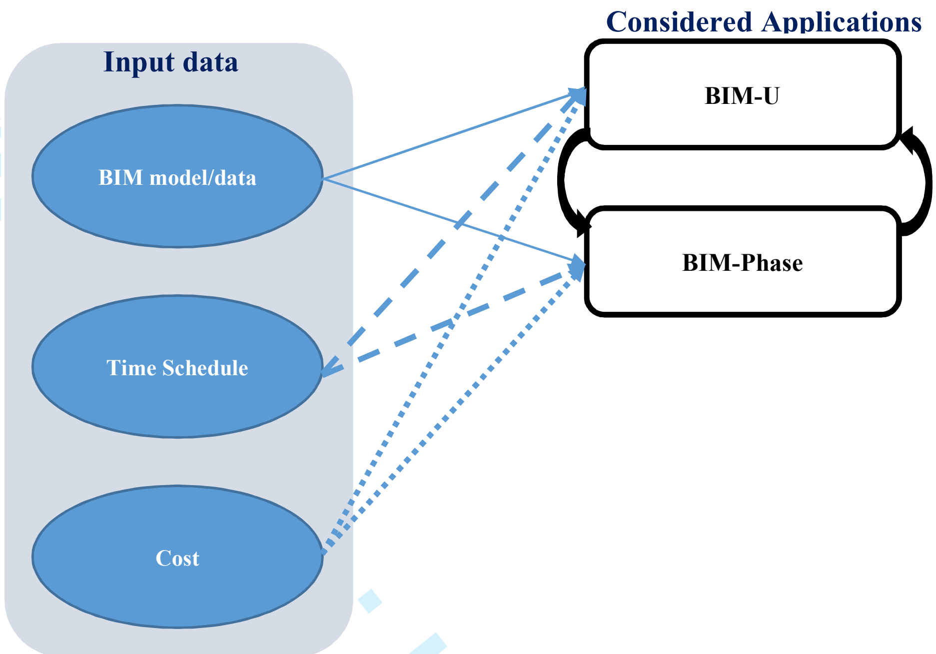

Figure 1 — Relation between the considered applications

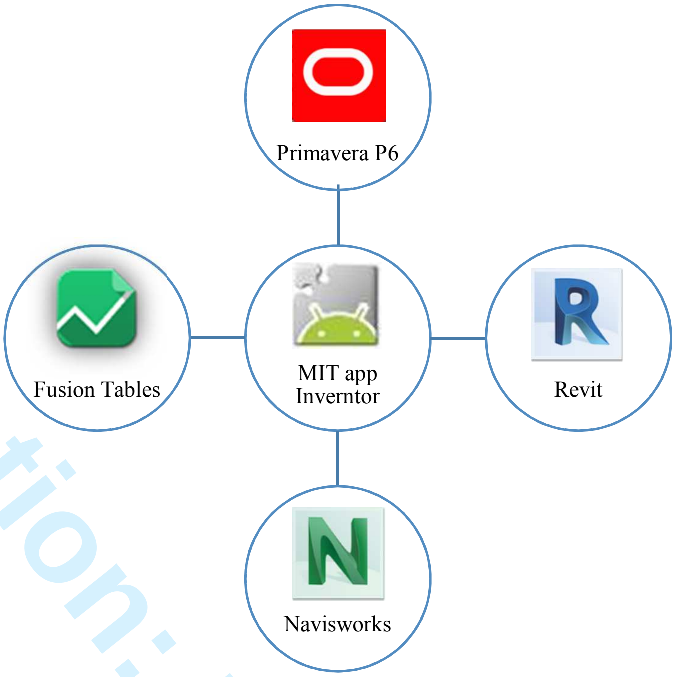

Figure 2 — Android application architecture

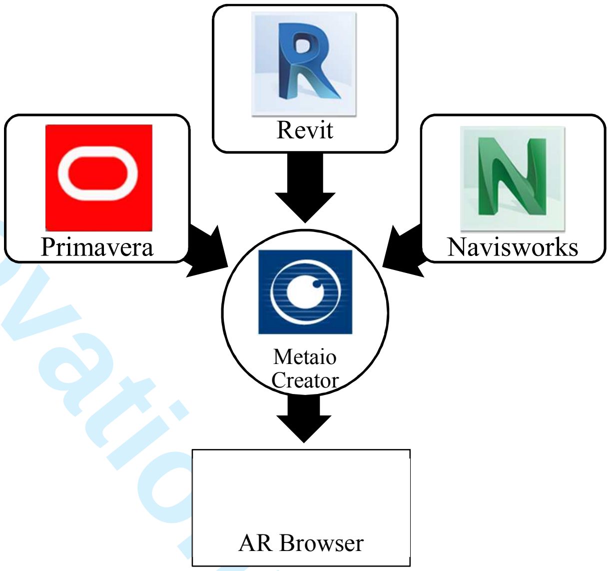

Figure 3 — Architecture of the proposed Augmented Reality application

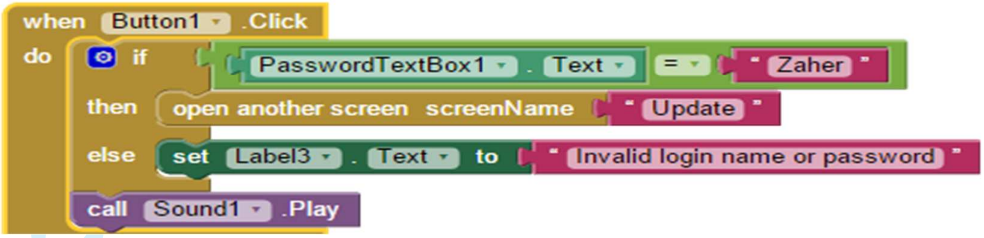

Figure 4 — Login screen programming block

WBS Code	Activity Name	Actual Start	Actual Finish	Progress
C.M2.B1.2ND.C	Steel Reinforcement For Slab - Upper Layer	5/8/2014		0.2
C.M3.B3.2ND.C	Steel Reinforcement For Slab - Post Tension	4/16/2014		0.56
C.M3.B2.2ND.C	Shuttering For Slab	5/1/2014		0.6
C.M3.B2.2ND.C	Concrete Pouring For Columns	5/12/2014		0.7
C.M1.B2.F.3.1.C	PC Slab On Grade	5/3/2014		0.7
C.M3.C3.2ND.C	Steel Reinforcement For Slab - Upper Layer	5/14/2014		0.78
C.M2.C2.3RD.C	Shuttering For Slab	5/8/2014		0.8

Figure 5 — updating time schedules using Google Fusion tables

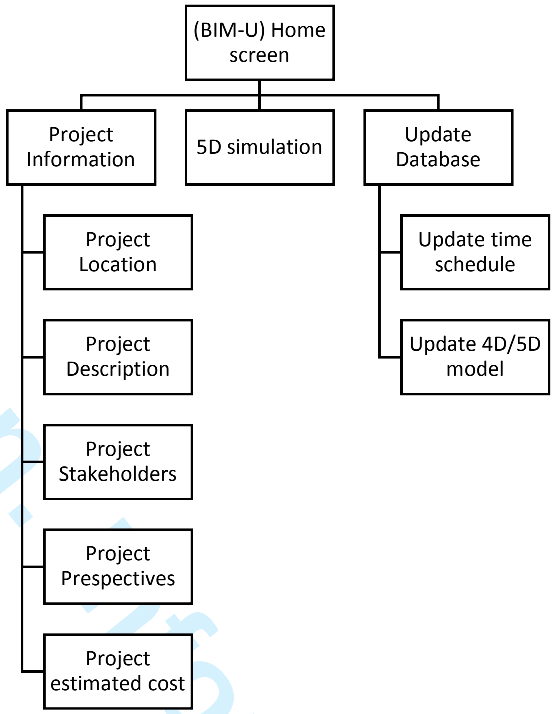

Figure 6 — BIM-U application tree

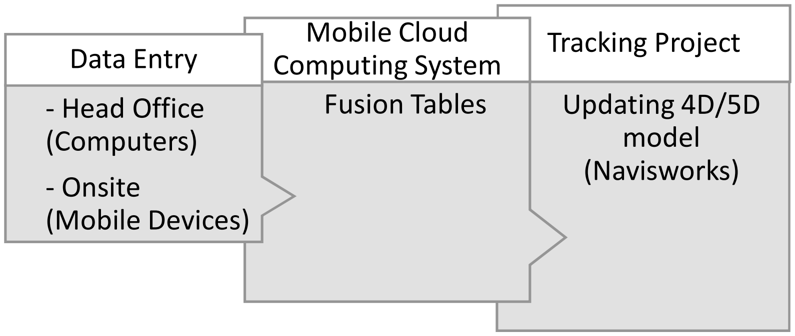

Figure 7 — BIM-U data flow

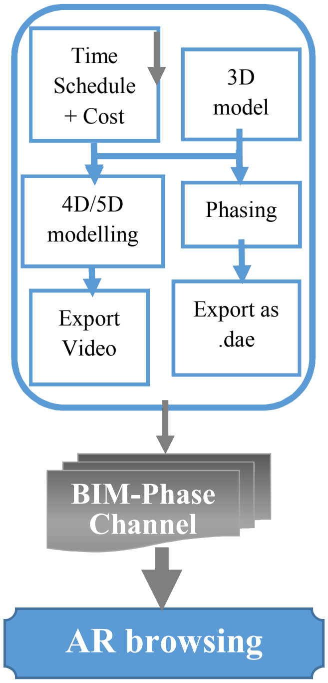

Figure 8 — BIM-Phase data flow

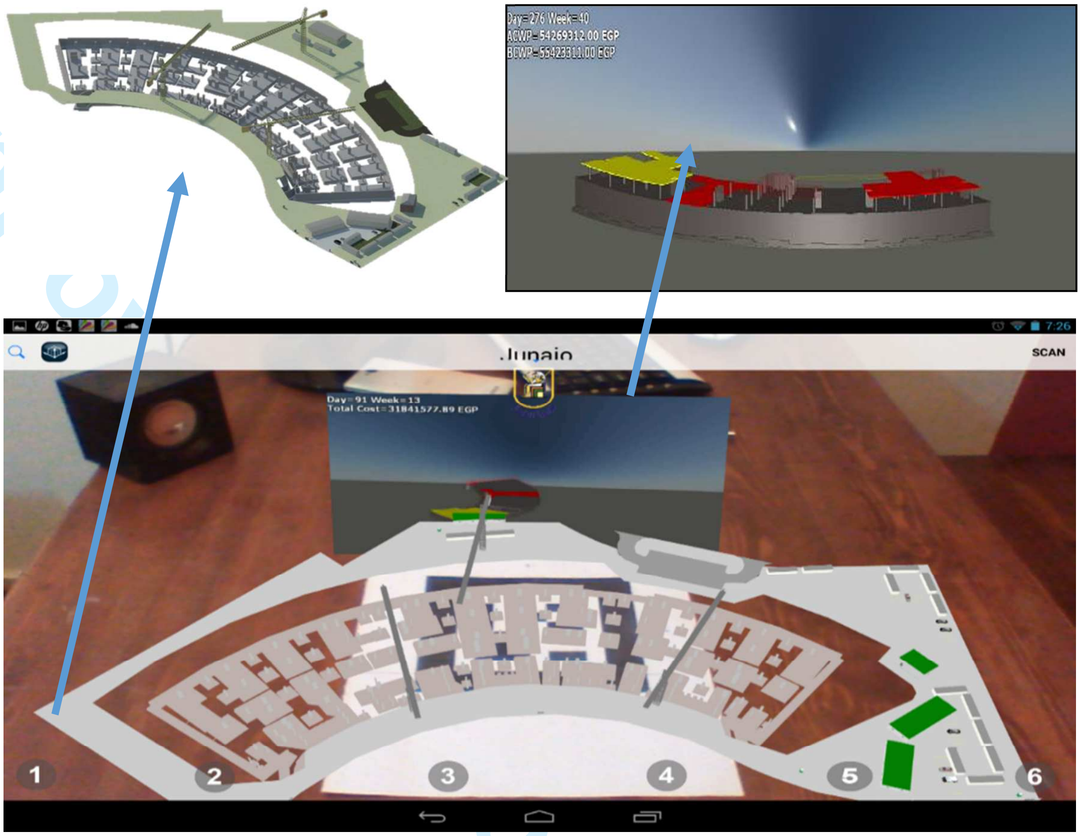

Figure 9 — 'BIM-Phase' AR Channel Creator

Reply to Reviewer 1 Comments

This reviewer's extensive and constructive remarks were much appreciated, and his/her all concerns and suggestions are now warranted. The responses to reviewer 1's comments are presented below:

Reviewers Comments to Author	Authors Response to Reviewers Comments
1. The author(s) proposed a new methodology for monitoring construction progress using smartphones, but I do not see anything new in this new application. BIM has been applied to construction projects for many years and project teams have already using this for tracking time and cost performance. The application proposed here is neither new, nor innovative at all.	It is true that BIM has been applied to construction projects for many years but the combination of BIM, AR, and handheld devices is still relatively innovative, and indeed, requiring improvement, particularly when this also extends to earned value analysis as well as traditional schedule monitoring. The novelty of the paper is specifically addressed at the start of the 'Conclusion' section (commencing 'What sets this work apart …')
2. The literature seems not comprehensive	The 'Literature review' section is restructured through subsections and this now includes updating some related work that is focused on AR applications in the field of AEC/FM that were developed in previous research.
3. No research method is described in the paper.	'Research Methodology' and 'Paper Structure' have been added in the introductory section. The method of implementing the system on an actual project emerges throughout its description.
4. It's not clear what is the benefits of adopting this app to the construction project. What is the reduction in cost and time after the adoption? As mentioned above, BIM is not something new and cloud technology has been applied to many construction projects. I do not see anything innovative from the results	As well as now containing an explicit discussion of its novelty (see above) the 'conclusion' section is revamped. The research adopted qualitative interviews that did not allow the authors to quantify the reduction in cost and time saving after adoption. However, it is highlighted in the 'Conclusion and future work' that future work shall be quantitative, in terms of measuring the accuracy or efficiency gains of the new system. The authors agree that BIM and cloud technology is not a new technology. The new edge is that cloud technology is here used for updating progress or any other important information of different areas in the project to update the time schedule regardless the scheduling tool (i.e. Primavera, Microsoft Project, Asta Powerproject, and so forth) used
5. The study in this paper provides very low implications for research, practice and/or society. I do not see any new and significant contribution of this study to the body of knowledge. Very low academic value	The paper has been restructured where major modifications were made to improve specific aspects of research rationale and illustrate the research implications through the added sections.
6. Proof-reading by native English speaker is required	One of the authors is native English speaker, and has now revised and corrected syntactical and grammatical mistakes.

Reply to Reviewer 2 Comments

This reviewer's extensive and constructive remarks were much appreciated, and his/her all concerns and suggestions are now warranted. The responses to reviewer 2's comments are presented below:

Reviewers Comments to Author	**Authors Response to Reviewers Comments**
1. However, in the current submission, the authors seems to have mostly focused on elaborating the case study and tools and mainly failed to demonstrate specific details of basic contribution to the body of knowledge and validation aspects. Also, the paper shall be revamped with removal of redundant details and figures and including articulation of concept, theoretical aspects and application potentials with feasibility overview.	The Research Contribution is now demonstrated through the paper and summarized in a separate section 'Related Solution'. The authors agree with the reviewer. So, redundant details and figures have been revised and/or removed.
2. Literature review is fine. Some updates in mobile technologies and AR/VR applications (even drawn from other sectors) will be more useful	The Literature Review section has been rearranged into subsections and updated with more related work.
3. Theoretical basis is somewhat weak and conceptual constructs shall be strengthened	Research methodology is now outlined in 'Research design' section
4. The descriptions in current draft mainly focus on development efforts and issues (as a case-study) and lacks soundness in elaborating the results and conclusions.	The case study is converted to, and described as 'a prototype' and results were elaborated through semi-structured interview
5. The research outcomes have high potentials for practical relevance. I would like to strongly encourage the authors to improve specific aspects of research rationale and resubmit with clear storyline	'The 'conclusion and future work' section has been revamped, and now includes a section that is more explicit about the novelty of the work, its implications, and follow-on work envisaged.
6. Writing quality is mostly fine. Most of the figures (except figures such as Fig 3, 4, 11, 12 & 13) are redundant screenshots with very low archive/ reference values to the readership. For demonstration purpose, 1 or 2 key screenshots are adequate! As there is not much coverage on facilities management, why this term was listed as a keyword in this manuscript? There are several such non-value aspects in this paper - which shall be carefully checked for improving the quality of this paper.	Only three figures now remain in the paper for demonstration. The keyword 'Facility management' has been removed and replace with 'progress monitoring' which we agree is more appropriate. The authors have removed many of the non-value-adding paragraphs and figures. The whole manuscript has been reviewed, proof-read and revised.

Mobile Augmented Reality Applications for Construction Projects

Abstract

Design/methodology/approach

This paper presents a new methodology for monitoring construction progress using smartphones. This is done by proposing a new system consist~~ing~~ings~~s~~ of a newly-developed application~~s~~ ~~called~~ named ~~"~~'~~BIM-Track~~BIM-U~~"~~' and a mobile Augmented Reality (AR) channel named ~~"~~'~~BIM~~ BIM-Phase~~"~~.~~'~~. ~~"~~'~~BIM-Track~~BIM-U~~"~~' is an Android application that allows the end-user to update the progress of activities ~~from a remote location~~onsite. This data is used to update the project's ~~4~~4D model enhanced with different cost parameters such as earned value, actual cost, and planned value. The ~~"~~'BIM-Phase~~"~~' application is a mobile ~~Augmented Reality~~ ~~(~~AR~~)~~ ~~application~~ channel that is utilised during construction phase through implementing a ~~4~~4D 'as-~~-~~planned' phased model ~~-~~integrated with an augmented ~~54D~~ video showing real or planned progress.

Purpose

Current researchers have attempted to ~~ease~~ facilitate the ~~monitoring~~ process of monitoring construction projects. Classic practice for construction progress tracking relies on paper reports, which entails a serious amount of manual data collection ~~and entails~~as well as the effort of imagining the actual progress from the paperwork.

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 ~~developed~~ system through ~~applications~~ ~~"~~'~~BIM-Track~~BIM-U~~"~~' and ~~"~~'BIM Phase~~"~~' exploits the potential of mobile applications and Augmented Reality (AR) in construction ~~Building Information Modelling~~ through the use of ~~smartphones~~handheld mobile devices ~~usage~~ to offer new possibilities for measuring and monitoring work progress using Building Information Modelling.

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Keywords:

Building Information ~~Modeling~~Modelling, Augmented Reality, Handh~~-H~~eld mobile devices, Construction Project~~s~~ Tracking, ~~Facility Management~~Progress Monitoring.

Introduction

Currently, handheld mobile devices~~smartphones~~ are being used for a wide variety different applications. In the construction context, this includes Augmented Reality~~ (AR)~~, and the portability and accessibility of handheld mobile devices~~smartphones~~ 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 ~~publicized~~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) ~~(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 p~~P~~rogress 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 et al. (2006) ~~(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 ~~smartphones~~ handheld mobile devices through explaining the development of new applications for tracking construction using BIM and AR. The proposed applications are demonstrated on a~~n~~ ~~actual~~ real construction project.

Research Design

This paper is an example of inductive research that started with observations from current practice. This research ~~strived~~aimed to explore the advantages of ~~to~~ utilis~~ing~~e handheld mobile devices ~~in the~~on construction ~~industry~~projects through integration ~~the~~of BIM and AR in a comprehensive system that allows users to monitor, update and visualise ~~the~~ construction time and cost performance~~schedule and visualise the updated BIM in an AR as well~~.

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The research hypothesis is that handheld mobile devices, when combined with other technologies provide a powerful system for construction progress monitoring using BIM. ~~(Iyer & Jha, 2005)~~ Iyer and Jha (2015) considered progress monitoring ~~as~~to be an important factor for ~~construction projects to~~ delivering construction projects on time and within budget. As a step towards improving construction progress monitoring on site, a system is proposed that allows ~~to perform beneficial reporting system to provide the opportunity for~~ project management to detect the performance deviations, which will in turn support their decision-making. The hypothesis is ~~proved~~tested ~~through~~by building, testing, and reviewing the proposed system of the featured applications on a real construction project ~~through~~using qualitative feedback from interviews. A semi-structured ~~format~~ interview format~~s~~ w~~ere~~as used in order to gain ~~held for gaining qualitative~~ richer information about participants' thoughts and opinions.

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Paper Structure

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This paper has seven sections. In this introductory section, the problem ~~was~~is described, the research hypothesis defined and the research methodology outlined. Section two presents a review ~~for~~of BIM, AR, ~~data~~ acquisition of construction data, and related work. Section three demonstrates the technical implementation ~~for~~of the featured mobile applications showing all ~~used~~ the key applications used.~~, where~~ S~~s~~ection four depicts the data flow within the developed applications. In Section five the prototype and the interviewee reactions to~~s~~ ~~results of~~ the proposed system are presented. Section six identifies~~y~~ the applications' potential, implications and possible leverages that ~~is drawn~~come from ~~applications' potential~~and its~~s for~~ practical relevance. Finally, section seven evaluates the system through interviews and address issues that ~~shall~~remain to be ~~covered through~~addressed in future work.

Literature Review

Building Information Modelling

Building Information Modelling (BIM) has become well-known in the construction industry. The ~~Building Information Model~~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 (Hergunsel, 2011). BIM has attracted global attention in Architecture, Engineering, Construction and Facilities Management (AEC/FM) since 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 1.

Insert Table 1

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% are 'aware and currently using BIM', 35% 'aware but not using BIM', and only 3% are neither aware of nor using BIM' (NBS, 2017).

Augmented Reality

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 Architectural, Engineering, Construction, and Facility Management (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 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% of the general contractors and 87% of subcontractors sampled were using mobile devices on their job sites to increase productivity (Bernstein & Russo, 2012): such uses ranging from the more obvious (such as cameras) to the

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more technologically advanced, such as sensing devices and GPS. The range of potential site uses for smartphones has been explored by Kim et al. (2103). ~~Kim et al.~~ ~~(Kim, et al., 2013)~~.

Typical practice for progress tracking ~~mostly~~ 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 ~~along with~~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 amounts of manual work that may affect the quality of the progress estimations (Kiziltas & Akinci, 2005).

To overcome such limitations, commercial ~~On the other hand,~~ 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

~~Literature Review~~

~~**Building Information Modelling (BIM) has become well-known in the construction industry.**~~

~~**The Building Information Model 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 (Hergunsel, 2011). BIM has attracted global attention in Architecture, Engineering, Construction and Facilities Management (AEC/FM) since there is growing evidence that adopting BIM increases efficiency and productivity.**~~

The present ~~study~~ section concentrates on ~~one aspect of the implications of BIM for AEC/FM processes~~the ~~developed~~ AR applications in the field of AEC/FM that ~~were~~have been developed in previous research, ~~where~~ some of ~~these~~which ~~applications~~ are computer--based.~~namely its use in construction management applications.~~

~~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 1.~~

~~*Insert Table 1*~~

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Building Information Modelling usage and awareness is on the increase. In the UK, for example, according to the fifth NBS National BIM Report in 2015 (NBS, 2015) and as shown in Figure 1, the advance, from 2010 to 2015, in BIM awareness and use is demonstrated. Currently, 48% are 'aware and currently using BIM', 48% 'aware but not using BIM', and only 5% are neither aware of nor using BIM'.

Insert Figure 1

In the USA, a 2012 survey revealed that 93% of the general contractors and 87% of subcontractors sampled were using mobile devices on their job sites to increase productivity (Bernstein & Russo, 2012)(Bernstein & 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. (Kim, et al., 2013). Augmented Reality 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).

Examples of distinctive AR/BIM applications that have already been developedimplemented include BIM2MAR (Williams, et al., 2015), (Zollmann, et al., 2014), HD4AR (Bae, et al., 2013), D4AR (Golparvar-Fard, et al., 2009) (Golparvar-Fard, et al.2011), AR4BC (Woodward & Hakkarainen, 2011) (Woodward, et al., 2010)(Woodward, et al., 2010) (Woodward & Hakkarainen, 2011), and D4AR (Golparvar-Fard, et al., 2009) BIM2MAR (Williams, et al., 2015).

(Williams, et al., 2015) Williams et al. (Williams, et al., 2015) Williams et al. (2015) developed an application called BIM2AR and conducted a pilot study of facility management at the Shepherd CenterCentre in Atlanta, Georgia, in a healthcare 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) Zollmann et al. (2014) introduced an approach for using AR for construction site monitoring. The authors developed methods for 3D reconstruction and aerial

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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 utilisation by using the image feature point as the basis for user locali~~z~~sation 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 augmented reality using images, taking 3-6 seconds for ~~localization~~ localisation and less than one hour for point cloud generation (Bae, et al., 2013).

~~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.~~ The A4BC application was implemented for mobile visualisation in various modes and along the timeline, masking the virtual model with real images through the Global Positioning System (GPS). ~~Woodward et al. (Woodward & Hakkarainen, 2011) (Woodward, et al., 2010)~~ 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, whilst the OnSitePlayer module is the mobile application used to visualise the model data on top of the real worldview using ~~Augmented Reality~~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.~~Williams et al. (Williams, et al., 2015) developed an application called BIM2AR and conducted a pilot study of facility management at the Shepherd Center in Atlanta, Georgia, in a healthcare 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.

A large number of AR development tools are available. Table 2 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 & Constine, n.d.). However, a range of substitute applications, listed in Table 2, are available for the different aspects of augmented reality for construction that are considered in this paper.

Insert Table 2

Recent Augmented Reality applications, including those shown in Figure 2, 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 GPS, orientation, face/image detection, 3D maps, and others. This research adopts the ID Markers tracking configuration. ID Markers are 2D markers with a black border (see Figure 2) that can be reliably detected in simple applications.

Insert Figure 2

On the other hand, applications have been developed for 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 user to open and save in various other formats — including Microsoft Project and Primavera (elecosoft, 2017) (Anon., 2016).

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Method of development of the proposed applicationsTechnical Implementation of the proposed system

The proposed system is advanced through developing a applications, 'BIM-TrackBIM-U' android application and a 'BIM-Phase' channel that can be viewed on Android and IOS as well. 'BIM-U' and 'BIM-Phase' are complementing each other as these applicationsfor use in a variety of

~~different functions, including~~ update work progress, ~~tracking and v~~visualise actual progress, and compare it with the planned model (see F~~f~~igure 1)~~ation~~.

Insert 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 ~~2015~~: This application is used to develop BIM models.
- Autodesk Navisworks ~~2015~~: This application is used for integrating the 3D model with a resource-~~-~~loaded ~~the~~ time schedule to develop the 5~~4~~D simulation in the project in various stages.
- 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 ~~Augmented Reality~~AR ~~applications~~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 2 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 & Constine, 2015). However, a range of substitute applications, listed in Table 2, are available for the different aspects of augmented reality for construction that are considered in this paper.

Insert Table 2

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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 ~~3~~2.

Insert Figure ~~3~~2

Figure ~~4~~ 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.

Insert Figure ~~4~~3

The '~~BIM-Track~~BIM-U' Application

~~BIM-Track~~BIM-U is an Android application that is superior to other commercial ~~developed~~ applications because the retrieved data can be used via an Excel spreadsheet to any other scheduling application such as Microsoft Project and Primavera. ~~BIM-Track~~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 relevant apps can be run without downloading any software to the computer. For viewing the designed application on the device, App Inventor Companion App 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. ~~Figure 5 depicts an example of developing a login screen using the blocks function.~~

~~**Insert Figure 5**~~

Insert Figure 4

~~Figure 6 shows the design interface for the same screen to grant access only to the users who have the log-in password.~~

~~***Insert Figure 6***~~

~~Effective tracking of site activities and retrieval of project information requires a user-friendly interface for the developed Android application. This research adopted two interfaces; the Android application and the AR application interface. The developed Android application start~~

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screen shows the options available to the end-users. Figure 7 depicts screenshots from "BIM-Track" - the developed application. The top left screenshot includes three buttons. The first button opens the essential information such as project's location, description, stakeholders, perspectives, and the estimated cost of the project. The second button opens a preloaded 4D model that is uploaded over the internet, and which is updated periodically through the same application.

As the data extracted from the application is used in for updating the 54D model, the 4D 5D4D/5D model visualises the difference between the planned and the actual progress of the project as detailed below. The third button is tapped to start updating projects activities. 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. .

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Insert Figure 7

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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. (Chi, et al., 2013) 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 PaaS (Platform as a Service) 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 8 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 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 application programming interface key (API).. All the data shown has been updated through the developed application, "BIM-Track".

Insert Figure 85

However, Fusion tables provided by Google can be 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-Track" through an API key. Programming

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~~*blocks as shown in Figure 9 are developed and validated to ensure correct working. The connection between the fusion table and the Android application takes place through application programming interface key (API).*~~

~~***Insert Figure 9***~~

The 'BIM-Phase' Application

The ~~4D 5D~~4D/5D model is the core of the ~~"~~'BIM-Phase~~"~~' channel application. A 3D model was developed for an administrative building using Autodesk Revit ~~2015~~ and integrated with time schedule prepared with Primavera R8.3 associated with the concrete budgeted cost for further controlling. This integration took place through Naviswork~~s 2015~~, which is used to ~~produce~~ export 4D model in .avi extension to be integrated with cost parameters as an augmented video through Metaio Creator. The ~~4D 5D~~4D/5D model can be periodically updated through the ~~BIM-Track~~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 5~~4~~D 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 ~~and be taken~~ 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/5~~4~~D model are assigned to an ID marker to be ready for Junaio channel generation to visualise an augmented 5~~4~~D video and 3D model for the project's phases. ~~Figure 10 depicts a screenshot for developing the AR application using the AR creator.~~

~~***Insert Figure 10***~~

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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 (BCWS) which is also known as the Planned Value (PV), Budgeted Cost of Work Performed (BCWP) which is also known as Earned Value (EV), and Actual Cost of Work Performed (ACWP). ~~-~~The ~~"~~'~~BIM-Track~~BIM-U~~"~~' application represents the difference between the aforementioned parameters through a 4D model and is thus used to ~~determine~~ visualise it in 'BIM-Phase' to ~~if~~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-Track~~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. Secondly, ~~BIM-Track~~BIM-U transfers these results to Google Fusion tables, as described earlier (see F~~f~~igure 5). Thirdly, 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~~Drive. Lastly, the final results are synchronised through the previous update to be imported into Navisworks after scheduling. The ~~BIM-Track~~BIM-U process is repeated as the data is collected and updated periodically. Figure ~~11~~ 6 depicts ~~BIM-Track~~BIM-U application tree that illustrates this data flow from the construction site to end-users. The ~~top left~~application has ~~screenshot includes~~ three ~~buttons~~screens. The first ~~button~~screen contains ~~opens~~ the essential information such as project's location, description, stakeholders, perspectives, and the estimated cost of the project. The second ~~button~~screen opens the updated ~~a preloaded 45D~~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.

Insert Figure ~~11~~6

Projects information needs to be updated periodically to track the projects' status, and this process takes place through the ~~BIM-Track~~BIM-U application as shown in Figure ~~12~~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).

Insert Figure ~~12~~7

In order to implement BIM-Phase, the applications pass through different phases. These phases are (1) Data collection phase, (2) Implementing phase, and (3) 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. Whilst, the implementing phase is for implementing the AR application using the acquired data to be ready for processing using Metaio ~~creator~~Creator. Finally, three different channels for the applications are generated on Metaio ~~creator~~ Creator to move to the visualising phase through Junaio mobile application. Figure ~~13~~ 8 depicts the data flow in BIM-Phase AR application.

Insert Figure ~~13~~ 8

Every AR application implemented using Metaio Creator has a channel with a QR code to be opened on the AR browser. Firstly, the user downloads Junaio mobile application from Google play or App store. Secondly, the user clicks on the scan button to scan the QR code. Finally, the AR implemented channel is viewed~~opens~~. ~~(see Figure 14).~~

~~**Insert Figure 14**~~

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~~Case Study~~Prototype for testing the featured applications

In order to test site progress tracking through the ~~BIM-Track~~BIM-U Android application, a ~~case study~~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-Track~~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. ~~Figure 15 shows a screenshot of the phone's data collection process together with a related Fusion table to which the data can be readily transferred over the internet using the cloud computing based service provided by Google.~~

~~***Insert Figure 15***~~

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The input data updated~~shown~~ in ~~BIM-Track~~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 Planned Value, Earned Value, and the Actual Cost of Work Performed for the activities, as explained in an earlier section. As such, Navisworks was able to export the 4D/5~~4~~D 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/5~~4~~D model was exported as a video to be presented in ~~BIM-Track~~BIM-U and BIM-Phase. ~~In this example 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 (see Figure 16).~~ These results were used to ~~calculate~~ compute important parameters in cost control management to check project status with respect to time and cost such as ~~. A~~ Cost

Performance Index (CPI) and Schedule Performance Index (SPI~~) are shown in the 4D model (see Figure 16~~). The~~se~~ results show that the project has an ~~under~~over-run in terms of the~~ estimated~~ project's budget, ~~but is~~and behind schedule as well (as the calculated CPI and SPI are 1.03 and 0.95, respectively) indicating any required recovery actions.

~~**Insert Figure 16**~~

In BIM-Phase channel application after updating the 4D/5~~4~~D model using ~~BIM-Track~~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 (see figure 9). ~~Figure 17 depicts the project phases rendered from the 3D model using Revit 2015.~~

~~**Insert Figure 17**~~

As shown in Figure ~~18~~9, an ID marker is printed to be used as trackable in order 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 projects' 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 Augmented Reality creator tool. When a button has tapped the model of each phase is rendered on the ID marker. In figure ~~18~~ 9 the rendered model represents the first phase. Moreover, behind the 3D model of the first phase, an augmented 4D/5~~4~~D 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 1) visualisation of the as planned 3D model in AR the adopting the project phases and 2) 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 (see Figure 9)

Insert Figure 9

The ~~considered~~ system's effectiveness was evaluated through ~~a~~ semi-structured ~~format~~ interviews with architects, planning engineers, cost control engineers, and site engineers. Individuals were chosen on a ~~where the criteria of selection based on~~ 'network selection' basis. The semi-structured interview was selected to identify several key questions c~~, where if c~~ompared to structured interviews it is considered as more flexible. The interview started with an introduction to the ~~presented~~ work. The key questions were 1) To what extent do you

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believe that AR has potentials in the construction management field?~~,~~ 2) H~~h~~ow can AR ~~aids~~assist in tracking construction projects?~~,~~ 3) Do you have any ideas ~~to~~for enhancing~~e~~ the presented work?~~,~~ 4) W~~w~~ho ~~is~~should be recommended to use the presented work?~~.~~ Generally, the participants ~~assured for the certainty~~confirmed ~~of~~ the potential of AR ~~potential~~ in the construction industry as it user-friendly and it is a tool that ~~s~~ 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. ~~Whilst regarding~~With regard to the present~~ed~~ work, the feedback received ~~is~~was that the ~~considered~~ system under consideration may: 1) reduce the time of explaining information, 2) reduce the time of construction, 3) decrease errors ~~because of~~compared with updating using paperwork, and 3) increase the satisfact~~or~~ion~~y~~ of the project's stakeholders through the facilitation in visualising information, which increases the effectiveness ~~rates~~ of~~n~~ decision-making~~ tasks~~. On the other hand, it was recommended to 1) integrate the whole system in one application, 2) improve the rendered model of 'BIM-Phase channel', and 3) address the time gap that could ~~happen~~occur between updating the time schedule and 'BIM-Phase channel'. ~~On the other hand, it~~It is recognised that there is a ~~massive~~considerable amount of work that ~~shall~~would need to be done prior to implementing the ~~considered~~ system. This work can be summarised in developing a BIM 3D model, time schedule, integrating cost model, and collecting data. It is likely, h~~H~~owever, ~~most probably, successful megaprojects~~that projects of a significant size will already have the 3D model which is the most time-consuming task. ~~***Insert Figure 18***~~

~~This augmented video can also be used to reflect the actual update for the 4D model from the site on a weekly basis. On May 17, 2014, which represents the day no. 373 in the project duration an update for the project's time schedule was performed. And thereafter, the updated time schedule using (BIM-Track) was imported in .CSV format to the Navisworks for synchronisation along with other additional data calculated with the Primavera. These data were the Planned Value, Earned Value, and the Actual Cost of Work Performed for the activities. As such, the Navisworks was able to export the Budgeted Cost of Work Scheduled (BCWS), Budgeted Cost of Work Performed (BCWP), and Actual Cost of Work Performed (ACWP) on the planned model to be exported to the (BIM-Phase) to monitor project and visualize the updated/planned 3D model.~~

~~**Related Solutions**~~

~~What sets this paper apart from others and provides it with a distinctive edge for construction projects is using a mobile application for updating progress through cloud computing based~~

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~~services using PaaS (i.e. fusion tables), which enable users to update the progress from different areas in the project using mobile devices regardless the used scheduling tool. According to (Zollmann, et al., 2014), AR does not allow for visualisation of as planned structure, however, 'BIM-Phase solve this issue allowing visualisation of as planned structure through phasing along with a 5D augmented video that provides different cost parameters tools to manage projects effectively.~~

Conclusion and future work

In this article, ~~a research~~the starting hypothesis was ~~defined~~ that handheld mobile devices, when combined with other technologies, such as AR, and using BIM, provide a powerful system for construction progress monitoring~~ using BIM~~. We proposed a system that allows ~~better~~enhanced project control through visualisation of construction progress ~~information of a construction site~~ directly on-site, using AR. ~~Smartphones, when combined with other computing technologies provide a powerful system for tracking construction projects using BIM.~~ The most stringent problems in the construction industry related to time, cost, and quality. ~~Building Information Modelling (BIM)~~The use of BIM alongside ~~with~~ handheld mobile devices such as smartphones and tablets has the potential to address these problems. A great deal of research has already utilised ~~Augmented Reality~~AR on Architectural, Engineering, Construction, and Facility Management (AEC/FM) projects, and examples have been presented. However, the current work presents a different technique of using the 54D in Augmented Reality.

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 ~~5D~~4D/5D augmented video that provides different cost parameter tools to manage projects more effectively.

This research has proposed a system that is adopting an Android application ~~has featured two new applications~~named '~~(BIM-Track~~BIM-U' and an AR channel named '~~and BI~~BIM-Phase~~)~~' that, if adopted, could ~~-~~have considerable leverages ~~can be used~~ in the construction industry~~ if adopted.~~ The architecture ~~proposed framework for~~of designing and implementing the applications was explained. These applications have different designated functions. The first,

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BIM-TrackBIM-U, is used for progress tracking and 54D modelling for the 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/54D model during construction with its essential cost parameters for bettermore effective monitoringtracking. These parameters are used to create compute time and costactual indices for schedule and cost performance, in the form of a Cost Performance Index (CPI) and a Schedule Performance Index (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 applicationssystem. Because of Tthe nature of the semi-structured interview approach, which allows ideas to emerge that hadve not previously been thoughtenvisaged by the research team. The, new ideas were generated by this study that will be addressed in Ffurther work. These include: such as visualising planned structure on the physical environment to figure out deviations between the actual progress and planned model. On the other sideAdditionally, there is the matter of improving the proposed systemis now necessary 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.

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Table 1: Examples of BIM tools for construction management

Product Name	Developer	BIM Use	Developer Web Link
Navisworks Manage	Autodesk	1. Clash detection 2. Scheduling 3. Coordination	www.autodesk.com
ProjectWise Navigator	Bentley	1. Clash detection 2. Scheduling 3. Collaboration	www.bently.com
DP Manager	Digital Project	1. Scheduling 2. Model review 3. Collaboration 4. Quantity take-off	www.digitalproject3d.com
Visual 4D Simulation	Innovaya	1. Scheduling 2. Coordination	www.innovaya.com
Vico Office	Vico Software	1. Scheduling 2. Coordination 3. Cost estimation 4. Quantity take-off	www.vicosoftware.com
Solibri Model Checker	Solibri	1. Clash detection 2. Coordination 3. Quantity take-off 4. Design review	www.solibri.com

Table 2: Augmented Reality (AR) Tools

Product Name	Manufacturer	Supplier Web Link
~~Metaio Creator~~	~~Metaio~~	~~http://www.metaio.com/~~
~~Junaio~~	~~Metaio~~	~~http://www.junaio.com/~~
Layar	Layar	https://www.layar.com/
Hyperspaces	AR-media	http://www.armedia.it/
Wikitude SDK	Wikitude	http://www.wikitude.com/
D'Fusion Studio	Total immersion	http://www.t-immersion.com/
ALVAR	VTT Technical Research Centre of Finland	http://virtual.vtt.fi/virtual/proj2/multimedia/index.html
maxReality	Vuzix	https://www.vuzix.eu/
ARToolKit	DAQRI ARTruth Co. Ltd.	http://artoolkit.org/

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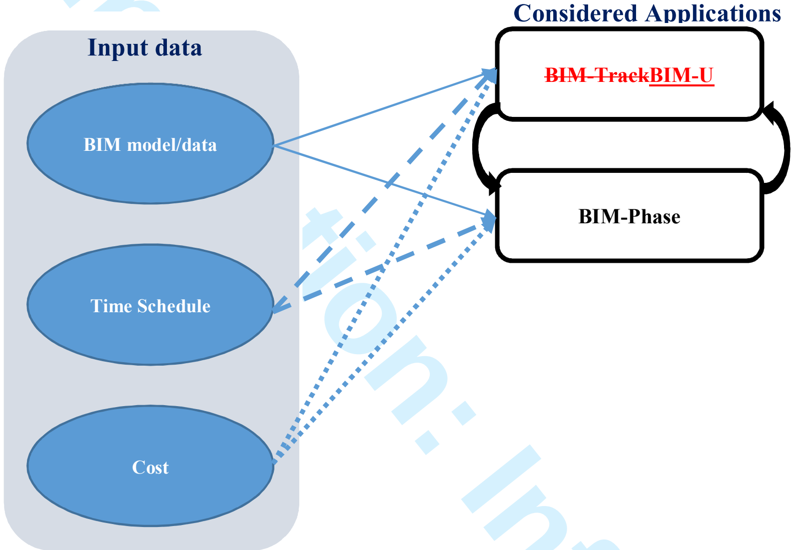

Figure 1 — Relation between the considered applications

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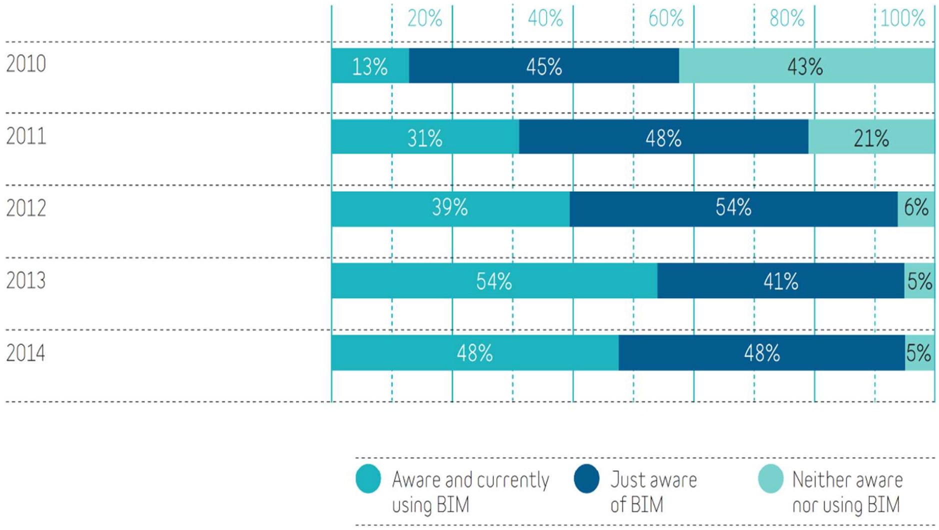

Figure 1 BIM awareness survey: source - NBS [5]

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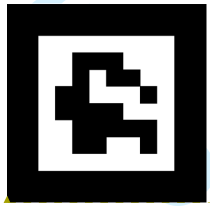

~~*Figure 2 — ID marker sample*~~

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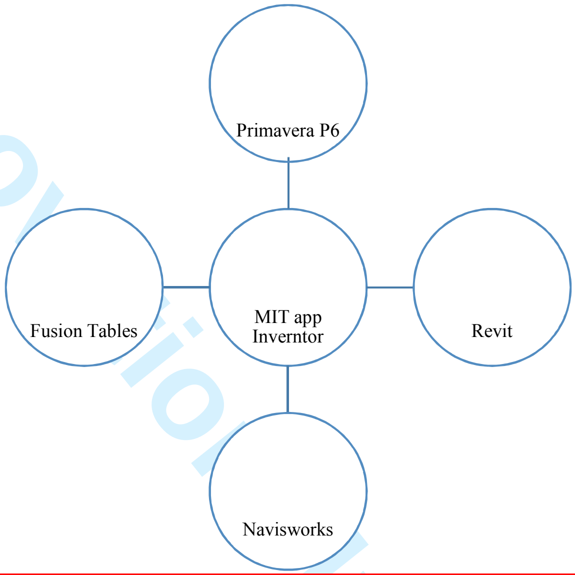

Figure ~~3~~ 2 — Android application architecture

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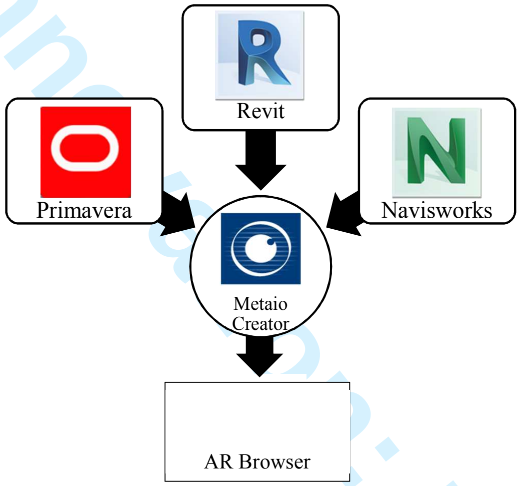
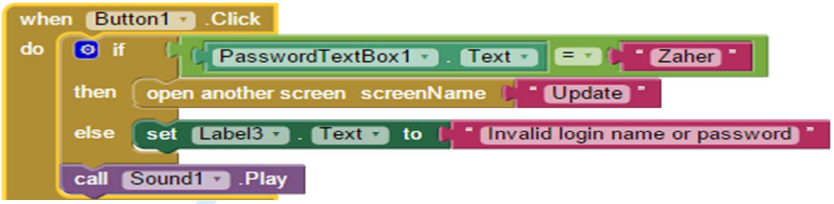


Figure 4-3 — Architecture of the proposed Augmented Reality application



~~*Figure 5 — Login screen programming block using MIT app inventor*~~

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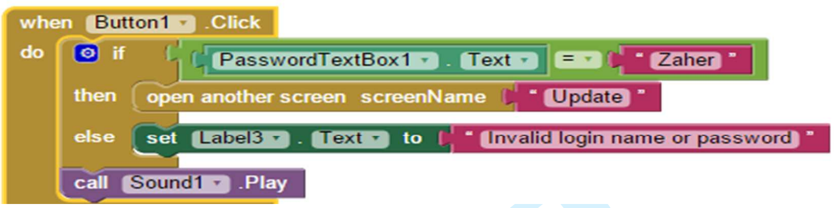

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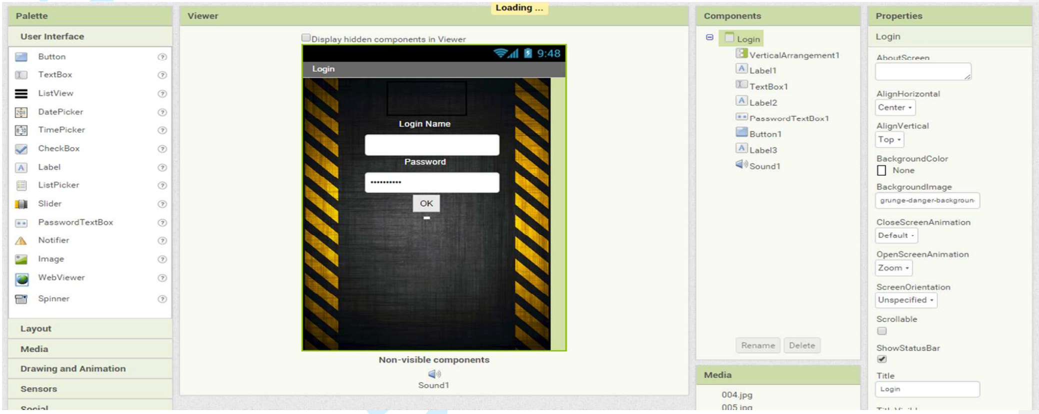

~~Figure 6 Login screen designer interface~~

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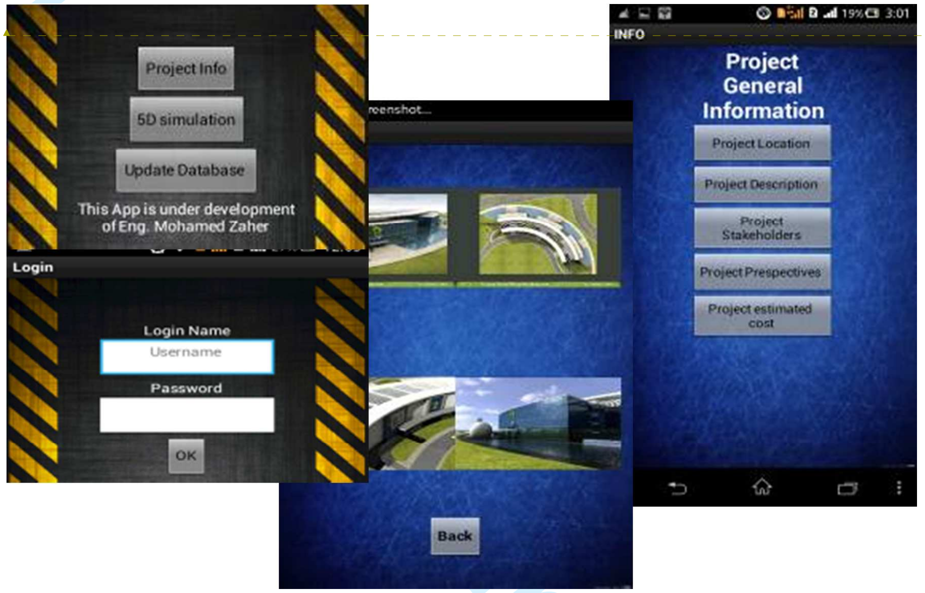

Figure ~~7~~ 4 — Login screen programming block ~~Developed Android application screens~~

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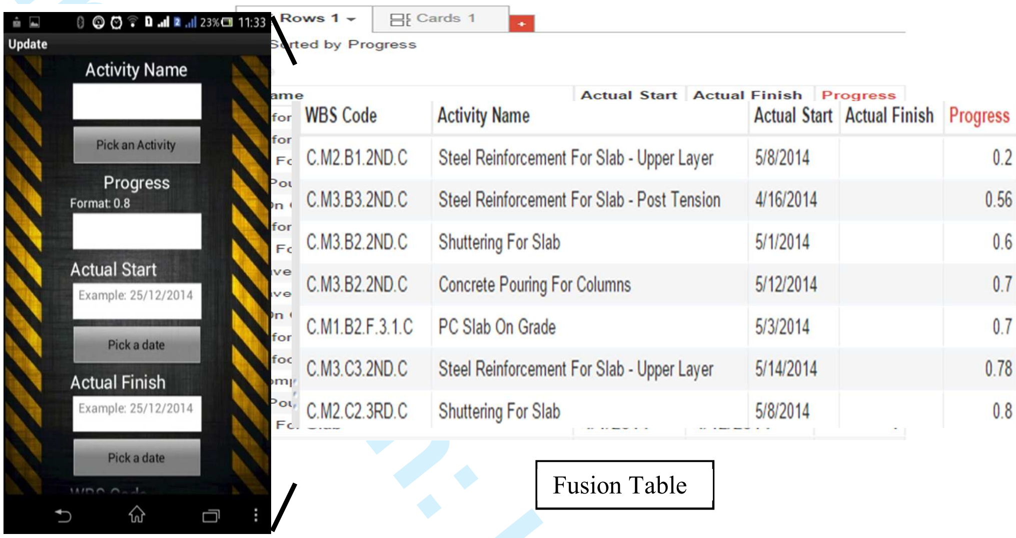

Figure ~~8~~ 5 — updating time schedules using Google Fusion tables

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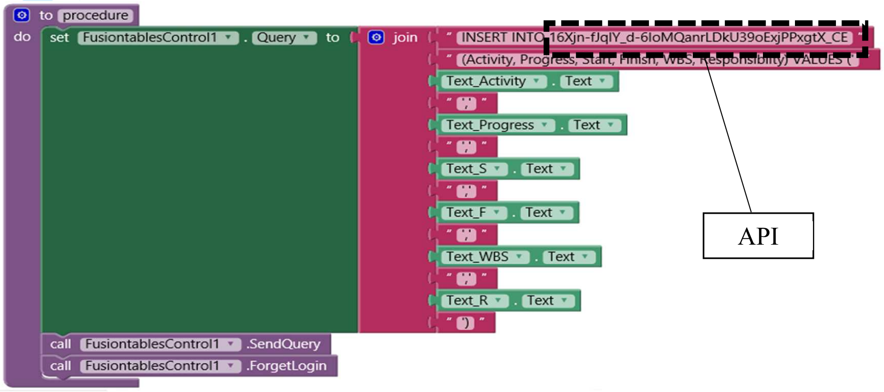

~~**Figure 9 — Fusion tables programming blocks in the Android application**~~

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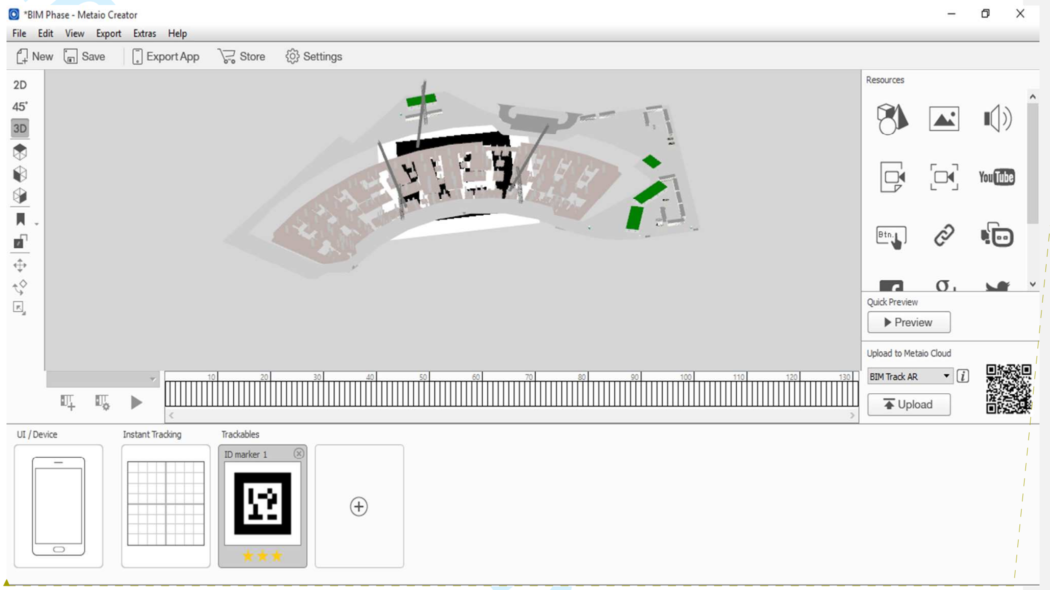

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~~Figure 10 — Augmented Reality Creator~~

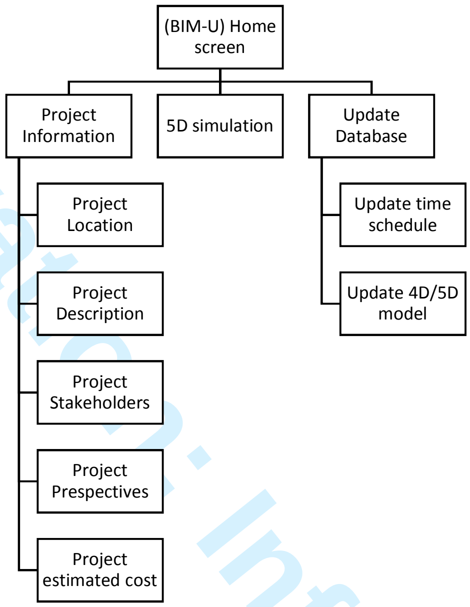

Figure ~~11~~ 6 — ~~BIM-Track~~BIM-U application tree

~~**Data Entry**~~ ~~• Head office (Computers) / Onsite (Mobile devices)~~
~~**Mobile Cloud Computing System**~~ ~~• Fusion Tables~~
~~**Tracking Project**~~ ~~• Updating 4D model (Navisworks)~~

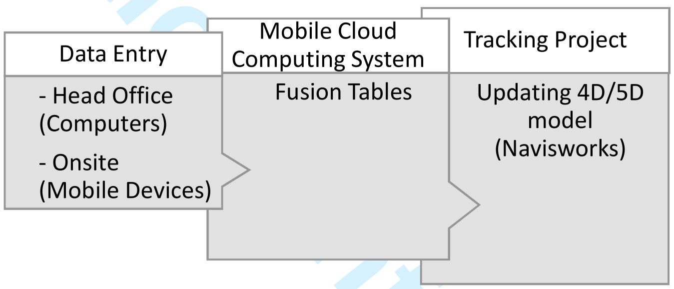

Figure ~~12~~ 7 — ~~BIM-Track~~BIM-U data flow

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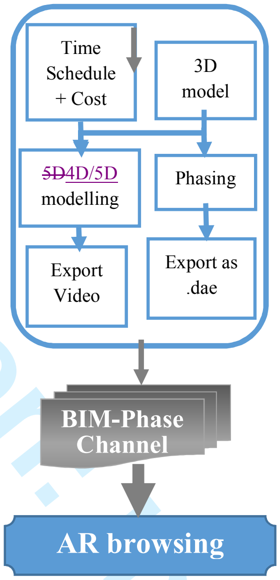

Figure ~~13~~ 8 — BIM-Phase data flow

~~Figure 14 AR application interface prototype~~

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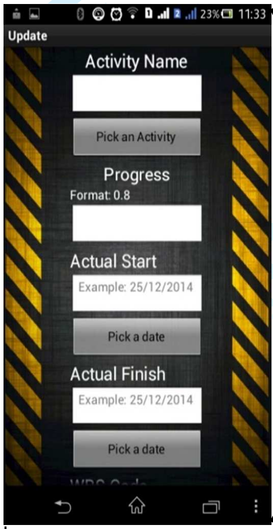

WBS Code	Activity Name	Actual Start	Actual Finish	Progress
C.M2.B1.2ND.C	Steel Reinforcement For Slab - Upper Layer	5/8/2014		0.2
C.M3.B3.2ND.C	Steel Reinforcement For Slab - Post Tension	4/16/2014		0.56
C.M3.B2.2ND.C	Shuttering For Slab	5/1/2014		0.6
C.M3.B2.2ND.C	Concrete Pouring For Columns	5/12/2014		0.7
C.M1.B2.F.3.1.C	PC Slab On Grade	5/3/2014		0.7
C.M3.C3.2ND.C	Steel Reinforcement For Slab - Upper Layer	5/14/2014		0.78
C.M2.C2.3RD.C	Shuttering For Slab	5/8/2014		0.8

Fusion Table

~~Figure 15 — Case study updating procedure (data collection process and related Fusion table)~~

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SPI= 0.94

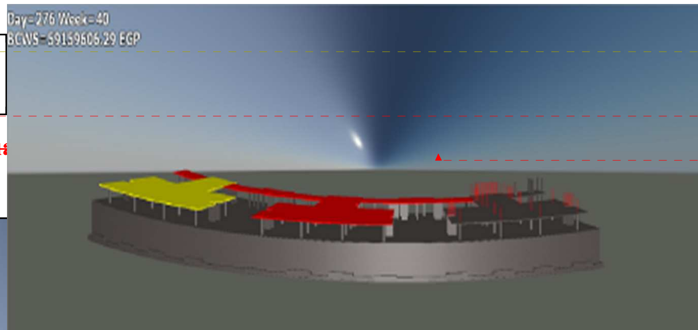
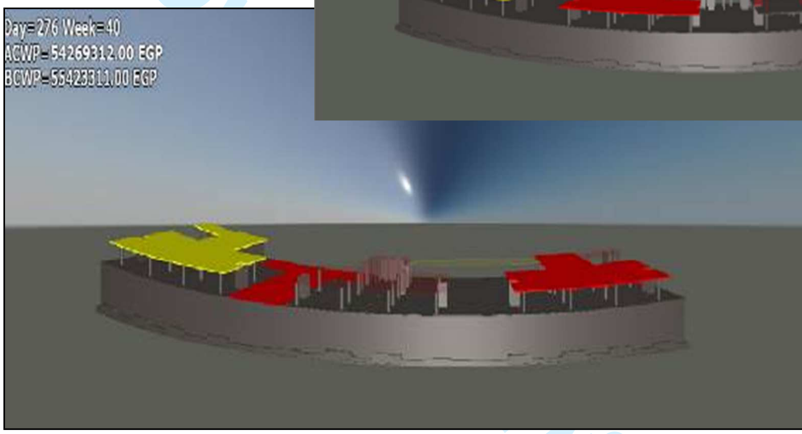


Figure 16 — 4D model visu



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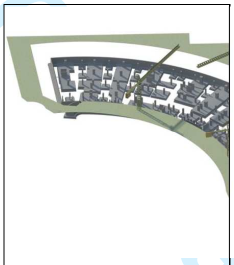
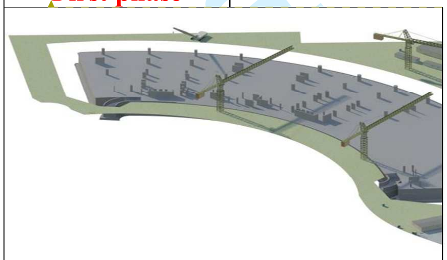
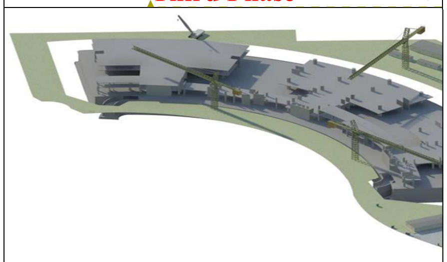


~~First phase~~

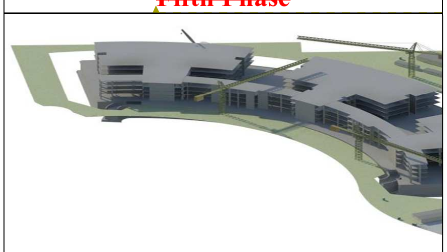


~~Third Phase~~



~~Fourth Phase~~

~~Fifth Phase~~



~~Sixth Phase~~

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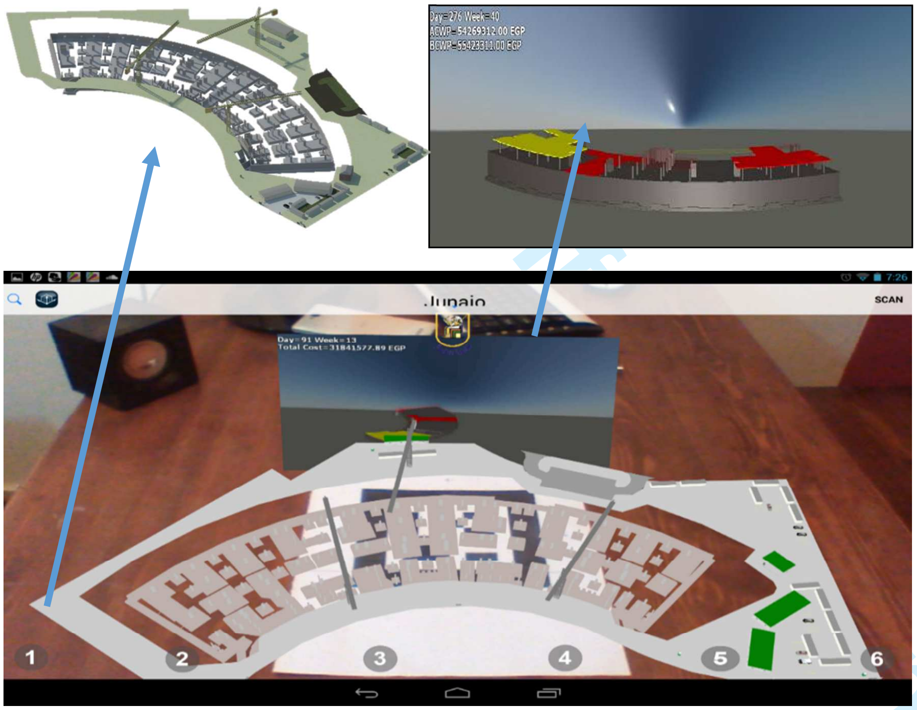

Figure 9 — 'BIM-Phase' AR Channel Creator~~Figure 17 — Project phasing in 3D modelling~~

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Figure 18 — 4D augmented video in BIM-Phase application