35 Augmented Reality Combined with Location-Based Management System to Improve the Construction Process, Quality Control and Information Flow

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Abstract

Efficient construction management is highly depending on respective persons in charge and their ability to steer the inherently complex flow of information. Communication among stakeholders is crucial to improve construction process management, which is usually managed by means of paper-based documents in most of construction sites. To improve on-time delivery of projects and automate construction management, the mobile application—AR4Construction was developed. It integrates technologies such as BIM and AR with Location-based Management System. This application aims to improve productivity, collaboration between project participants as well to provide tailored information to the user. This paper describes concept, framework and functionalities of the AR4C application as well as testing and validation phase.

Keywords

BIM • BIM metadata • Augmented reality • Location-based management system • Digital construction

35.1 Introduction

The construction industry (CI) is a project-based industry characterized by heterogeneity, extreme complexity, fragmented supply chain and variability of trade performance. It is widely recognized that the CI is one of the less efficient sectors, if compared to other industries like manufacturing. It was found that only 16% of construction projects are brought to the conclusion on time, within the budget, meeting all required quality standards [1]. In UK, 60% of construction project organizations struggle with time and cost overruns on more than 10% of their projects [2] This is due to inefficient and inaccurate monitoring and control processes [3]. According to [4], in the US, 10% of project cost is spent in one rework. The waste in construction is between 25 and 50% of construction cost and it is due to inefficient interaction between trades and control of labor and materials. Cost and time losses are caused by omitted errors in the design phase, which are detected afterwards on the construction site.

The CI is struggling with difficulties in sharing information between project participants, which is one of the most common causes of poor performance [5]. Since efficiency and productivity of construction processes depend mostly on the accurate and timely information availability on site [6], an efficient management of the information flow as well as improved communication are crucial to enhance construction processes. Along with the development of technology like Building Information Modeling (BIM), Augmented Reality (AR), Virtual Reality (VR) and Internet of Things (e.g. RFID, NFC), new

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I. Mutis and T. Hartmann (eds.), *Advances in Informatics and Computing in Civil and Construction Engineering*,
https://doi.org/10.1007/978-3-030-00220-6_35

hardware and software tools have been introduced to the construction industry. These tools allow the automation of construction processes and have potential for improving monitoring of construction works and management of information flow as well as for reducing construction errors.

35.2 Background

Information on construction sites is mostly exchanged by means of traditional methods such as phone, email and fax. However, these solutions have not solved communication problems so far, because information systems are still not integrated and characterized by a lack of interoperability [7]. In major construction sites, information is still managed by means of paper-based processes, which create some difficulties in keeping track of information and up to date [8]. Construction managers use also inadequate tools to visualize and represent the information [9]. This leads often to misunderstanding between stakeholders, construction errors and low ability to make rapid and right decisions. Construction managers are not able to focus on important task, because they spend 30–50% of their time to collect and analyze site data due to the manual methods for monitoring and controlling of construction works [10]. If successful progress monitoring is applied, it is possible to reduce execution schedule deviations up to 15% [11], project cost up to 10% [12] as well as cost of reworks, claims and disputes [13].

Recently, the adoption of computing and communication technologies in the CI has had a significant impact on both productivity and economic growth of construction companies. BIM is one of these technologies, which allows the automation of several processes during the construction phase and has shown the potential to control construction project effectively. On the market, there are available commercial software based on BIM technology like Autodesk BIM 360 Field, Dalux, BIManywhere, etc., which can be deployed on mobile devices like tablet, smartphone.

Another promising technology is AR, which has undergone an important transformation towards more use-friendly solutions for mobile devices. This technology has potential to improve scheduling process. It is possible to show as-planned and as-built project and visualize the construction progress [14]. Ref. [15] found out that AR can facilitate the understanding of project documentation, construction progress through 3D visualization of models on site. AR is also useful to improve communication between experts and investors [15]. Ref. [16] proposed a solution for markerless mobile-based AR using HoloLens to assist inspection and progress monitoring for interior activities by displaying 3D as-planned BIM model and detecting differences with actual construction. Ref. [17] developed the ACCEPT system for construction management, which uses smart glasses and smartphone to display digital model and information in AR, which are overlaid onto real construction environment. Also commercial software for construction management are integrating AR technology. Autodesk Field 360 is working with DAQRI to display tailor content and documents using smart helmet. In last year Dalux released TwinBIM application, which allows user to see and interact with 3D model in AR using a smartphone. Sublime provides a prototype of AR solution using HoloLens or DAQRI to monitor and visualize construction process and to guide workers through the installation process. BIM and AR technology increase automation of controlling processes on site as well as improve decision-making process and provide real-time access to information. Nevertheless, to achieve more efficient construction process, BIM-based tools combined with AR and Lean Construction (LC) methods are required. The application of LC methods such as Location-Based Management System (LBMS) with BIM technology can improve construction processes. LC methods are promising to reduce, if not completely eliminate, non-value-adding works. LBMS was able to achieve a duration compression of 10% using schedule optimization [18]. Ref. [19] evaluated that LBMS is able to increase production rate on average 37% and prevent production problems by 50%. Several researchers have attempted to integrate LBMS into construction management systems such as VisiLean [20] and KanBIM [21] to improve construction processes and scheduling reliability. Nevertheless, most of software for LC management are not available on mobile devices and are not compatible with AR technology.

35.3 Proposed Solution

The main goal of the AR4C project is to investigate how AR combined with BIM and LBSM can enhance the management of information flow, monitoring of the construction process as well as communication among project participants on the construction site. Research activities on the AR4C application are based on the European project—ACCEPT (www.accept-project.com) and they are currently carried out by Fraunhofer Italia and Free University of Bozen-Bolzano within the Ph.D. Programme “SET”.

This paper describes concept and functionalities of the AR application for the construction site. It is still under development and the preliminary testing within a group of experts was conducted and described. Further testing in real conditions (construction sites) and calculation of impacts on the construction process, quality and information flow are planned and they are shortly mentioned in this paper.

35.3.1 Concept of the AR4Construction Application

The AR4C application is addressed mainly to site managers and workers and it is envisioned to provide them with context-aware information at anytime and anywhere on the construction site. Information delivered to the user is as follows: (a) 3D BIM model overlaid onto real world objects; (b) component/material technical data; (c) assigned construction tasks in a specific location; (d) assembly instructions; (e) quality checklist to verify performed work; (f) construction process KPIs for each location on site. The AR4C is developed for the Android smartphone Lenovo Phab 2 Pro. Initially, different devices were considered like smart glasses (e.g. HoloLens), but finally smartphone was chosen, since it is low cost device, it does not disturb the user mobility and safety on site and the interaction with the device is more familiar, if compared to other head-mounted devices. Another advantage of the Lenovo smartphone is the integration of the Google Project Tango technology like motion tracking, area learning, and depth perception. These technologies give the ability to understand the device position relative to the world around it with high precision and accuracy.

35.3.2 AR4Construction: System Architecture

To create the AR4C prototype, Unity was chosen as the main development environment. The application is composed of several components (Fig. 35.1) like: (a) **3D model Management**; (b) **Data Management**; and (c) **GUI Management**. It is necessary to import external assets to component (a) and (b) like 3D BIM model (.fbx file) and its metadata via .xml file, respectively. Component (c) allows the visualization of 3D model in AR and related information within the Graphical User Interface (GUI). External APIs are integrated with Unity: (a) **Tango SDK**, which provides different features to gather information on the device position and orientation and to interact with it; (b) **Firebase SDK**, which stores digital assets like images, video, checklist, drawings, messages and allows the AR4C application to access them whenever needed. It acts as digital data repository of the application.

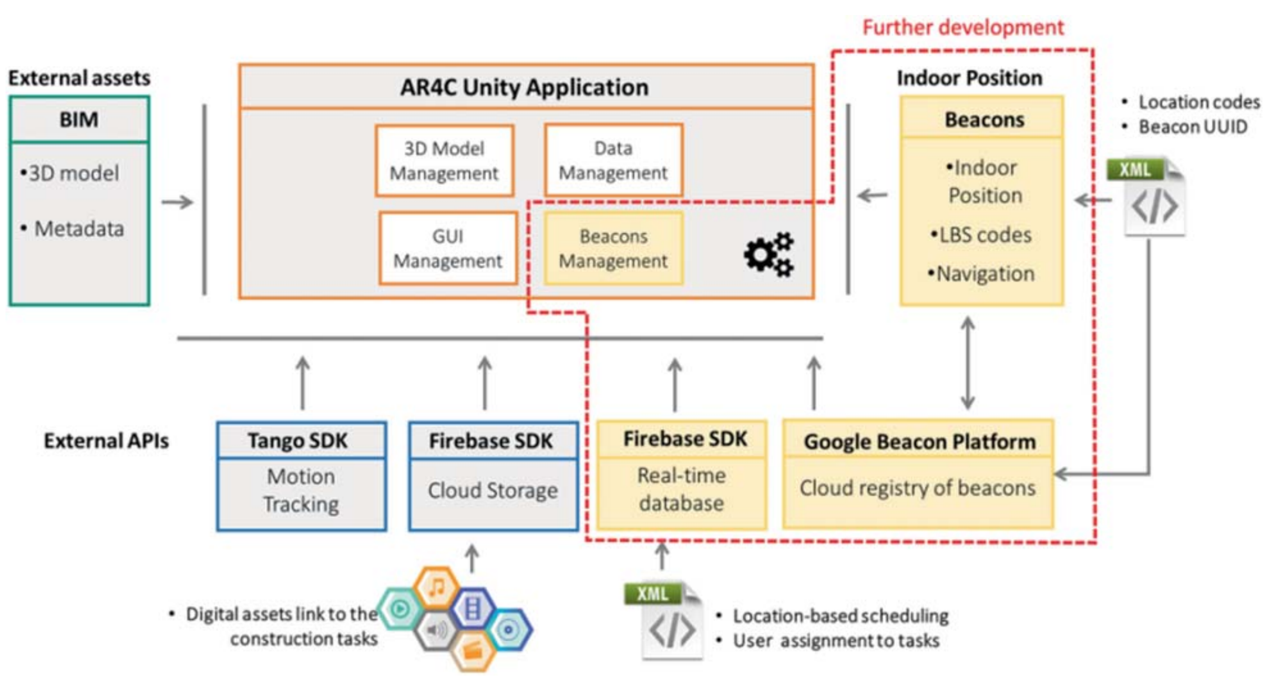

Fig. 35.1 AR4C system architecture

Components related to locations of the construction project and to task assignment according to LBMS will be implemented in further developments of the AR4C. The identification of construction locations will be done by means of beacons. It will be done by placing them in predefined construction locations with correlated location codes. In addition, a scheduling database linked to location codes will be required.

35.3.3 Integration of BIM and Scheduling Data in AR4C

To enable the integration of LBMS in AR4C application, it is necessary to link construction tasks to building components and materials in a BIM model in a specific location defined in the construction project. Such connection allows a graphical representation of where construction works should be executed and how they are progressing. While a worker is walking though the construction site with the AR4C application, he should see in AR assigned tasks to him on the 3D model aligned with the surroundings. When he clicks on a task, related components/materials are highlighted on the model and information on installation process is displayed (Fig. 35.2). Digital assets linked to construction tasks are stored in Firebase service.

To link BIM components with respective tasks in the specific location, the system of WBS code (WBS – Work breakdown Structure) and LBS code (Location Breakdown Structure) was developed. It assumes that the master schedule of the construction project is prepared considering these codes. The same codes are also inserted in related components/ materials in the BIM model. The combination of both codes provides a unique nomenclature for each task, so-called WBS/LBS code, which is used to identify the specific task in the specific location. In BIM software, 3D geometry data and respective metadata with codes are exported via .xml file and imported to Unity. Afterwards, data can be managed by the AR4C application. Since Google Project Tango technology can recognize only physical location defined by position and orientation, it will be necessary to make AR4C application identify locations defined by LBS codes. It will be done be means of beacons placed at the construction site. This part is currently under development. It is planned that the AR4C application will allow site manager to monitor construction process KPIs (progress, productivity and performance) in different locations. KPIs will be visualized by means of widgets, graphs displayed within the location on the 3D BIM model. The measured KPIs related to assigned tasks will be as follows: (a) current activity progress [%]; (b) PPC [%], (c) Performance Ability

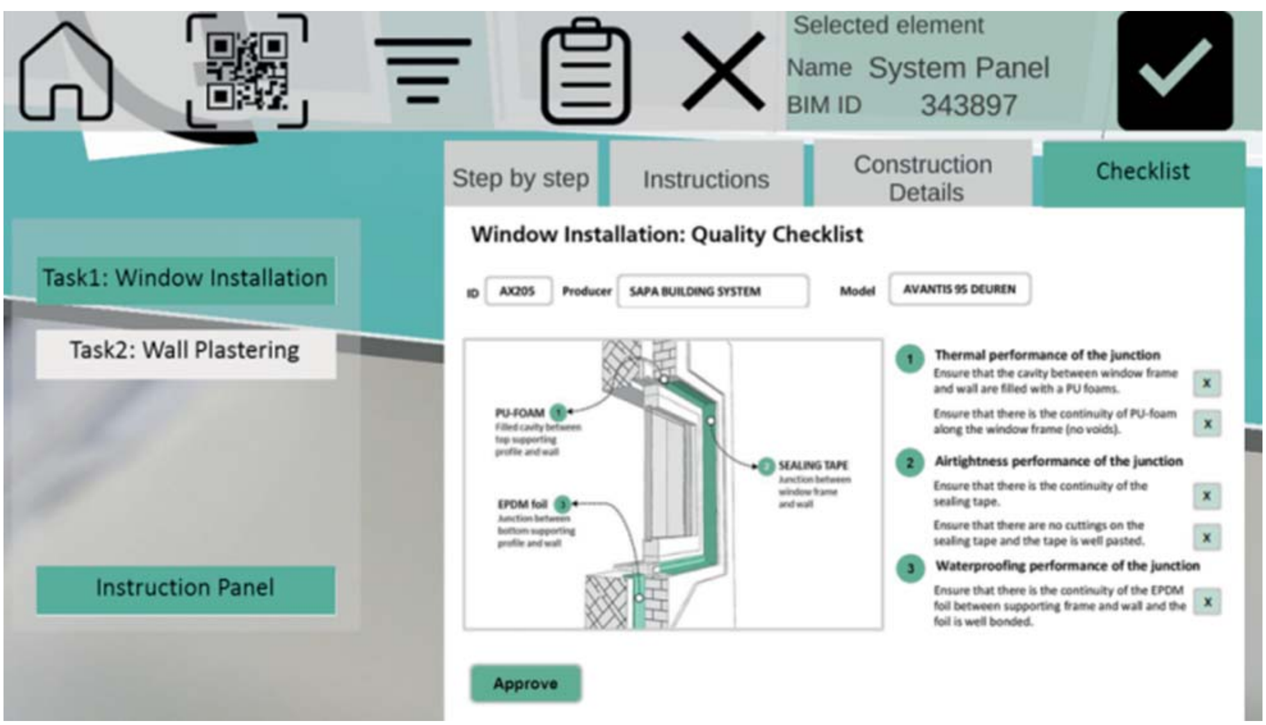

Fig. 35.2 Visualization of tasks and related information

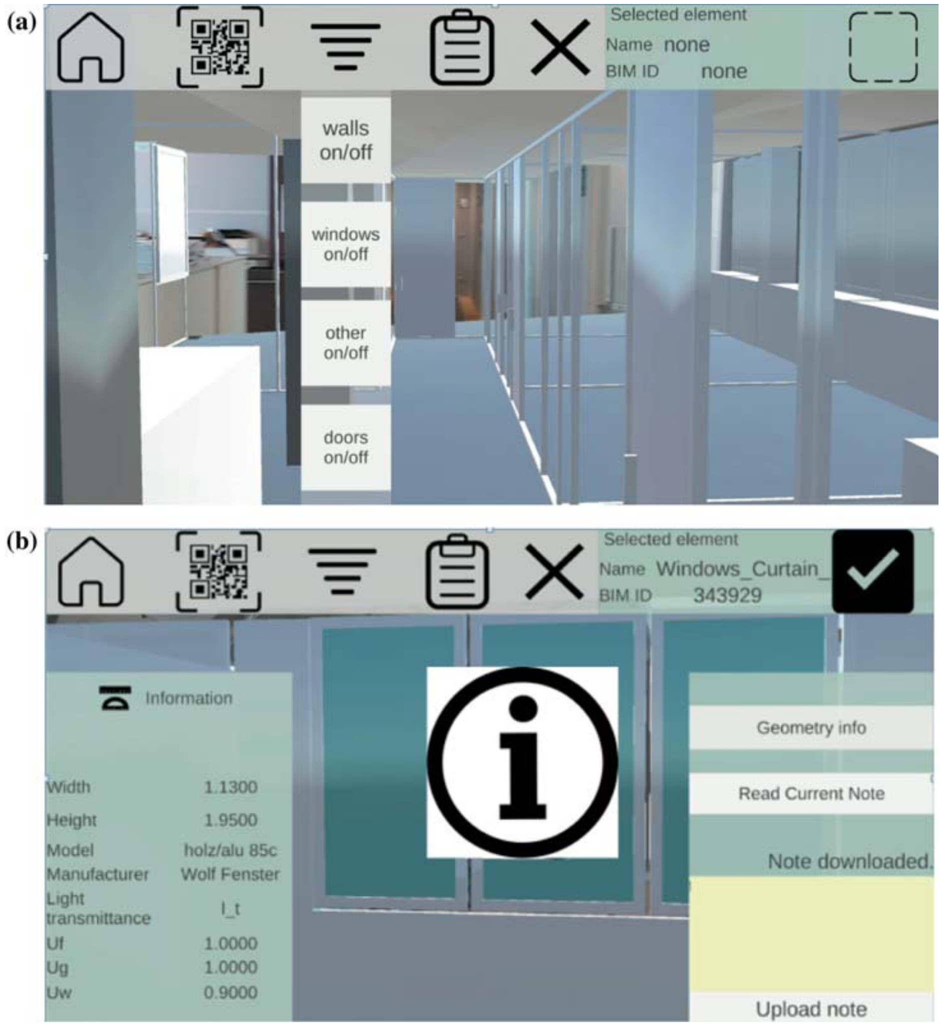

Fig. 35.3 AR4C: **a** 3D model in AR; **b** Information displayed for selected components

Ratio—PAR [-]; (d) Reason for non-completion—RNC; (e) cumulative delay [days]. Values of these KPIs are calculated based on input data collected by the Construction progress checklist (Sect. 3.4, point 3).

35.3.4 AR4C Functionalities

The AR4C application is under continues development. So far, the following functionalities have been implemented:

1. **Display and explore 3D model based on the user position**. The user can start displaying 3D model in AR by launching the application in the same physical position as it was defined in the virtual model. Afterwards, the user can move around. The model remains aligned with the surroundings, since the application is using motion tracking technology. The user can interact with the 3D model by clicking on objects and switching on/off group of components, therefore see only objects of interest (Fig. 35.3a).
2. **Touch objects to access quickly information on building components.** When the user touches an object on the 3D model, it is highlighted in green. By doing so, the user can access general information about the geometry as well as physical and technical data of the selected component. This information is displayed only if it has been embedded in the BIM model beforehand (Fig. 35.3b).

3. **Display the scheduled tasks and related information**. Based on the user position on the construction site, the worker can see a list of tasks that have been scheduled for him on a weekly basis. By clicking on the task, the information panel appears. It provides the following types of information: (Fig. 35.2): (a) **Step by step** tab, which shows steps that should be followed by a worker in order to perform a work according to the rule of the trades; (b) **Instructions** tab, which shows a document with installation procedures that can be scrolled down; (c) **Construction Details** tab, which contains construction drawings and details; (d) **Checklist** tab, which contains a quality checklist that should be filled out by a worker at the end of the task.
   In further development, there will be integrated also Construction progress checklist tab, which will be used to report the construction progress at the end of the day. The worker will provide input data regarding the percentage of completed work with respect to the established daily goal of assigned tasks. This input data will be used for calculations of construction process KPIs displayed for the specific locations to enhance the project controlling and inspections done by site manager directly on site.
4. **Create and read virtual notes attached to building components**. The user can use this functionality to attached comments, report issues related to the specific building component. Firstly, the component has to be selected on the 3D model and afterwards the massage window appears. The user can write down a massage and upload it to Firebase. It remains available and can be displayed any time, once the component is selected.

35.3.5 Testing and Validation

The AR4C application was tested in two buildings in the area of approximately 200 m^2, focusing mainly on the calibration of the 3D model alignment with the real building. The motion tracking technology used by the application allows the tracking of the user position without using GPS signal. However, its precision was not always accurate. The testing consisted in the definition of the starting point (x, y, z) for the application in the real world (Fig. 35.4a). The same position was applied to Tango camera in Unity. Theoretically, it allows the perfect alignment of both real and virtual worlds. However, some differences were noticed between real position of the user and the position computed by the device. Such difference was variable and approximately varied between 0,4 and 1 meters. After testing the following assumption were stated. The lack of perfect alignment is caused by: (a) incorrect setting of the Field of View (FOV) of the device's camera and the FOV of the Tango camera; (b) problems with the perfect positioning of the device at the starting point. The initial error related to the starting point propagates further computation errors of the device position. Another alignment error was occurring, when the

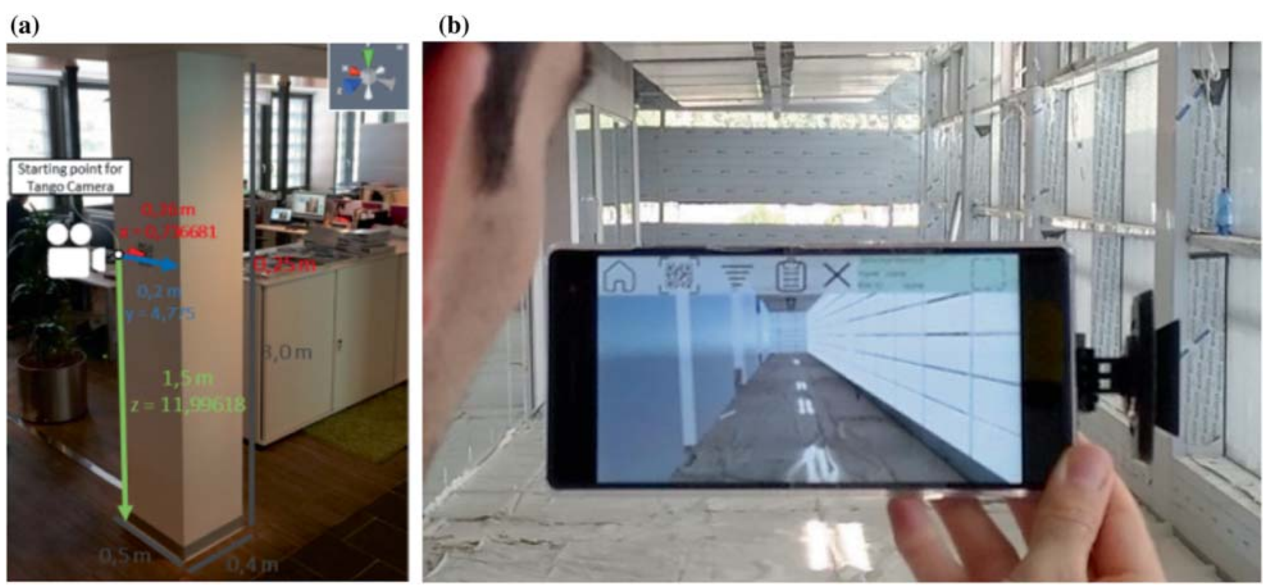

Fig. 35.4 Application testing: **a** definition of the starting point for AR4C; **b** alignment of the virtual model with the real building in the construction environment

user was reaching the surface of virtual objects. In this situation, the model visualization was blocked and the computation of the device position was affected, resulting in model misalignment. In further application development, all these issues will be investigated and adjusted.

The second part of testing was focused on the user acceptance. The application was tested within a group of 14 experts form the construction sector, who were asked to use the AR4C and fulfill afterwards a questionnaire. The questionnaire contained 25 questions related to functionalities, usability, utility of the information on the construction site that AR4C provides and graphical user interface. According to respondents, all functionalities met defined functional and non-functional requirements. All respondents ranked their interaction with the system as clear and intuitive. Organization of displayed information was considered good, nevertheless several feedback on the GUI improvement were reported. Almost all respondents considered that it is very likely that the information provided by the AR4C prototype will allow a faster access to relevant information on site and will improve the productivity of the construction process, if the monitoring of construction works will be implemented. Half respondents answered that it is likely that through the use of AR4C, an improvement in the overall communication between stakeholders involved in a construction project and error reduction can be achieved. As further development, it is planned to conduct testing in construction site to evaluate the qualitative and quantitative impact of this application on the construction process and building quality. Beyond the user acceptance the further tasting will focus on measuring: (a) KPIs related to the construction progress and performance calculated from input data provided by workers using AR4C; (b) number of avoided errors due to installation instruction and visualization of the 3D model overlaid onto the real world. All these data will be used to estimate cost savings generated by improved processes, quality and information flow. To provide realistic data and estimations, the application and its functionalities will be tested on the construction site of the polish general contractor—Budimex S.A. A specific use case will be selected (e.g. office building) and several construction tasks will be monitored in different locations. Workers and site managers will be also asked to test the application to evaluate its usability. The special focus will be put on the construction process monitoring according to LBMS and the integration of KPIs that can support effectively the management of construction works.

35.4 Conclusion

This paper describes concept and functionalities of the mobile AR application for the construction site, so-called AR4C, which runs on the Android smartphone—Lenovo Phab 2 Pro. It provides users with context-aware information related to the construction project like 3D model, technical features of building components and materials, list of construction tasks, installation procedures as well as quality and construction progress checklists. The application integrates Lean Construction methods like Location-based Management System (LBMS) in order to support the efficient management of construction works on site. Tasks displayed in AR are linked to the specific location of the construction project, to BIM elements. To link BIM components with respective tasks in a specific location, the system of WBS code (WBS—Work breakdown Structure) and LBS code (Location Breakdown Structure) was developed. Moreover, the AR4C application allows users to create virtual post ‘its, which can be attached to the virtual model and read any time by different users. The preliminary functional testing and validation were carried out in two buildings. It was found that even though Lenovo smartphone uses the computer vision technology, some important differences were found in alignment of the virtual model with the real building. The application was tested also by a group of specialists, who provided a good feedback regarding the usability and utility of the application. They agreed that the AR4C application should improve communication by providing a faster access to relevant information on site. It is also likely that it will improve building quality by avoiding construction error and the productivity of the construction process, when the monitoring of construction works will be implemented. The qualitative and quantitative impact of this application on the construction process, quality and information flow will be tested on real construction site carried out by the general contractor—Budimex S.A. in Poland.

Acknowledgements The authors would like to thank Andrei Popescu for IT development of the AR4C. The development part was described in his bachelor thesis at the Free University of Bozen-Bolzano: “Context-Aware Information Delivery for the Construction Site Using a Mixed Reality Mobile Application”.

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