Development of a Digital Platform Based on the Integration of Augmented Reality and BIM for the Management of Information in Construction Processes

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Abstract. The construction industry is a project-based industry characterized by heterogeneity, extreme complexity and fragmented supply chain. Its complexity is increased by mutual relationships between different stakeholders involved in the creation, management and efficient exploitation of engineering data. Over the years, productivity and reliability in CI has been struggled by a difficulty in sharing information between construction project participants and in providing accurate information on site, which is a primary cause of poor performances.

Therefore, the adoption of enabling tools for managing product data and information flow as well as for better communication and collaboration appears crucial in the CI. This paper describes an approach to achieve significant improvements in managing of construction activities, thanks to the adoption of ICT technologies for the immediate information delivery. In particular, this research paper will describe the developing process of a digital platform that uses augmented reality combined with BIM to provide workers with relevant information in real-time, based on their current position on the construction site. This consists in a 3D model-based integration platform that can integrate and exploit BIM models, in order to provide context-aware "augmented" information in real-time at the right place.

The paper describes the main features of the developed tool and focuses on the actual topics of the study which are: (1) the location system using sensory information collected by mobile devices to give location awareness to the application; (2) the integration of 3D BIM model metadata in order to contextualize tasks and instructions and provide building components information.

Keywords: Augmented reality · BIM metadata · 3D model-based platform Industry 4.0 · Product development

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1 Introduction

1.1 Construction Industry

The Construction Industry (CI) is an information-based industry, since a great amount of information need to be transferred and exchanged during the construction process. Its peculiarity regards the management of different challenges given by multiple parties participating towards the completion of a construction project. Construction processes are characterized by an extreme complexity, where various participants must collaborate, exchange information and often solve problems. Over the years, the CI has always been struggled by difficulties in sharing information between the involved participants. This fact represents a primary cause of poor performances. Different participants would spend a major effort on the individual work, rather than intelligently exchanging information with other parties [1]. Moreover, in major construction sites, information flow still depends on paper-based information management. Such aspect can easily result in misunderstanding between stakeholders [2]. Therefore, an efficient management of information flow is crucial to encourage a general improvement of construction processes.

1.2 ICT Technologies and Augmented Reality in the CI

In the most recent years, the adoption of ICT in the supply chain management has brought significant improvements in industries. The increasing digitization of information management in the Construction Industry is examined in [3] as an opportunity for new technologies to find valuable employment also in construction processes. The source states that while information is being more and more treated in a digital format, there is also the necessity of accessing and visualizing it in an intuitive manner. Several studies have therefore considered mobile applications integrating Augmented Reality technologies, as valid digital tools in the Construction Industry.

Augmented Reality (AR) is an emergent technology which allows the creation of a 3D virtual layer upon the reality, that enhances the normal experience of the user. Especially on the construction site, where a high level of flexibility is required due to rapidly changing conditions, there is urgent need of suitable information management support that can adapt as rapidly. Different studies argue that mobile applications integrating Augmented Reality technologies have the capabilities to satisfy such need, because they provide meaningful and updated information with respect to space and time [4]. Additionally, human perception is based primarily on three-dimensional objects. Therefore, a digital 3D representation supports a quick orientation in space and can be used to provide information in a context-based manner [5].

Building Information Modeling

Building information modeling (BIM) is a set of interacting policies, processes and technologies that generates a methodology to manage the essential building design and project data in digital format throughout the building's life cycle [6]. For more than ten years Building Information Modeling has been one of the most important innovation means to approach building design holistically, to enhance communication and collaboration among key stakeholders, to increase productivity, and to improve the overall quality of the final product (building) [7]. The integration of AR with BIM models can furthermore improve the assimilation of this innovative practices, making possible the exploitation of model-based software tools. Building models together with the encapsulated metadata, can conveniently be accessed and managed with an AR mobile application [8].

2 State of the Art

Many researches have focused on developing, analyzing and discussing different solutions for managing BIM data and information flow using digital enabling tools. Mobile computing has been the topic of different studies, as one promising technology which would extend the information management from offices to the actual site [9]. As described in the paper, managers would therefore be able to remotely collect information from the site. An example of another valid solution is [10], which aims to introduce the effectiveness of Google Glass as a technology for the information management on the construction site. One further study [11] analyses the inadequate management of resources in the CI, and discusses a framework for the implementation of the Virtual Reality technology with the purpose of data visualization. Such system would display real-time information in the virtual model, in order to avoid its manual monitoring.

As [12] writes, the real challenge lies in the provision of the position in time and discusses different indoor positioning techniques, their characteristics as well their accuracy, advantages and disadvantages. Only in recent years the focus has passed to indoor venues, and one technology identified for indoor location is Bluetooth. Positioning with BLE beacons has two major purposes, tracking and providing local-based services [12]. Indeed, BLE is a different and innovative solution for developing an indoor positioning system (IPS), by defining a real-time and environment-adaptive signal propagation model, based on the evolution of Received Signal Strengths Indicator over time.

Different studies have also considered mobile applications as useful instruments for the processing of BIM information. An effective theoretical input comes from [13], which discusses the possibility of integrating construction information coming from BIM software with Augmented Reality. As this study suggests, AR should include context awareness, in order to properly manage all BIM information.

It is also important to keep in mind the field of application, in order to provide enabling tools that properly addresses the construction site issues. It appears crucial to consider the dynamics in the construction site, where workers are in continuous movement and on different positions of interest. For example, [14] proposes a high-precision, image-based AR application for collecting information from the construction site, aiming at reducing the manual work. Generally, as [3] states, even if the idea of applying Mixed Reality in construction is not particularly new, a simple straightforward solution has not been yet available.

3 AR4Construction Research Project

Considering the discussion above, the final goal of the project AR4Construction has been identified in the development of an enabling tool for managing technical information in a dynamic and intelligent manner, in order to solve the issue of the rapid changes occurring on a construction site, that require immediate information delivery and ease of use. The main aim was to develop a mobile application for the digital transfer of BIM information on the construction site, though augmented reality and exploiting an indoor location system based on Bluetooth technology.

The application domain was defined to be a generic construction site. The application permit to visualize the whole, or only parts (e.g. windows), of the 3D BIM model in the "correct" place while walking through the construction site, and furthermore to extract relevant information in the construction phase (details or assigned tasks). The idea is to provide workers with a user-friendly digital tool which substitutes a consistent amount of paper-based material.

According to this, functional requirements are designed as follows:

- Users of the application are workers on the construction site;
- Explore the 3D BIM by walking in the real counterpart. The position of the worker in the building should always correspond to the position in the 3D model;
- Be able to filter the building components (e.g. walls, floors, windows), therefore to see only interesting components;
- Touch relevant components in order to access its information. This includes general information about the geometry and physical details but also specific notes attached to that component;
- Visualize tasks to be completed with respect to the worker position in the 3D model.

4 Development

Once the definition of the requirements and functionalities of the system has been completed, a conceptual scheme of the application structure was designed in order to support the implementation phase. The internal structure, considering the hardware and software components and the information flow of the AR4Construction platform was defined (Fig. 1). This section aims to describe the tools, the procedures, and various issues concerning the system's whole development phase.

4.1 Internal Structure

Among different hardware solutions available at the time of this research, the smartphone "Lenovo Phab 2 Pro", that integrates the platform "Tango", has been chosen as the mobile delivery device. With regard to the development environment, the application has been implemented in Unity, that allows the creation of system's required blocks and their interaction by means of C# scripts. The Unity game engine platform is essentially required for the 3D model management. The implementation's preliminary phase consisted of importing the necessary services and assets into Unity, such as the Tango API, the Firebase SDK, adopted for the creation of a remote database and its

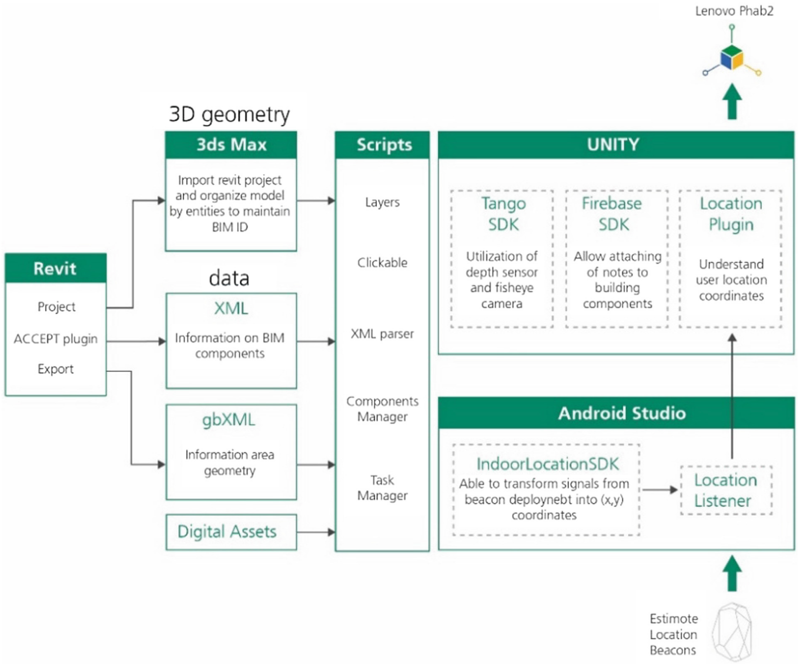

Fig. 1. Internal structure and information flow of the AR4Construction platform (Source: Fraunhofer Italia)

management through Unity, and a BIM model with associated XML metadata-file containing all building's relevant parameters. The development phase has been done using as a reference the BIM model of the Fraunhofer Italia offices, modeled by the authors. Thanks to this, each implementation step has been followed by a concrete testing phase inside the building.

The implementation advanced by developing a system to regulate all information incorporated in the model and metadata. For this purpose, the main work has been done in developing scripts that the authors called "Layers", "Cliccable", "XML parser", "Components manager" and "Task Manager". In such a way, data is available within the application for visualization and further processing. Furthermore, an Indoor Positioning System (IPS) has been structured exploiting the iBeacon technology, developing a script in Android studio, that the authors defined "Location Listener", that is able to transform signal from beacon deployment into coordinates.

An elementary Graphical User Interface (GUI) was consequently implemented in Unity in favor of convenient data handling. The GUI's features include a filter for the model's components, information retrieval by clicking the model's components and the possibility to insert component related notes. In the final phase, by means of the Firebase Storage Service, a cloud database has been created, in order to centralize all data that is relevant for multiple system's users.

In addition, the focus research topics of this paper are explained in the next section.

5 Research Focus

5.1 Indoor Positioning

Indoor Positioning System

Developing an AR application requires the understanding on the environment in order to offer contextualized information. The understanding required for the correct functioning of the developed application is related to the user positioning inside the building. To overcome potential complications deriving from the utilization of GPS systems, especially in complex environments, Indoor Positioning Systems (IPS) were here taken into consideration. There are many different approaches available to implementing IPS, and for this purpose the use of BLE (Bluetooth Low Energy) beacons has been chosen as the most suitable solution. Estimote Location Beacons were chosen as the hardware for the AR4Construction IPS.

Setting up Location Beacons

With the capabilities of the beacons in mind, a physical location was mapped. The most appropriate location for this purpose has been defined as the kitchen of the Fraunhofer Italia offices (Fig. 2). The area span is 4.5 by 9.1 m. Five beacons were placed at chest height, with a clear line of sight between each of them. An origin point was chosen, which serves as a point of reference for the beacons. After the positioning phase, a file with all relevant beacon information was uploaded to the Estimote Cloud.

This file serves to describe the relative placement of the beacons in terms of the origin point. Using this information, it is possible to calculate the position of a device found inside the frame of reference.

In order to gauge the setup accuracy, a testing phase followed. The smartphone (delivery device) was randomly placed in the mapped area and the position reported by the beacons has been compared with the actual real location. The measurements are shown below (Table 1).

During the testing phase, it was noted that for displacements less than 3 m, the software would not update the location. A large displacement in position triggers a recalculation. After the initial calculation, an error correcting phase occurs, until the estimated position converges to a fixed point.

5.2 Information Management

The 3D BIM Model Import Process

Fraunhofer Italia has provided the BIM model of the offices which correspond to the physical area mapped with the beacons. In order to import a BIM model in Unity, it must be in either .obj or .fbx format. Since the project file has been developed through the software Revit®, it must be transferred through 3DSMax® to be translated to FBX. The component names from this phase include an ID that links to the 3D elements. This model is then imported into Unity, where a camera displays it on the device screen. A camera in Unity is a device that captures and displays the view to the user. This camera has a three-dimensional position in the scene, which determines what is

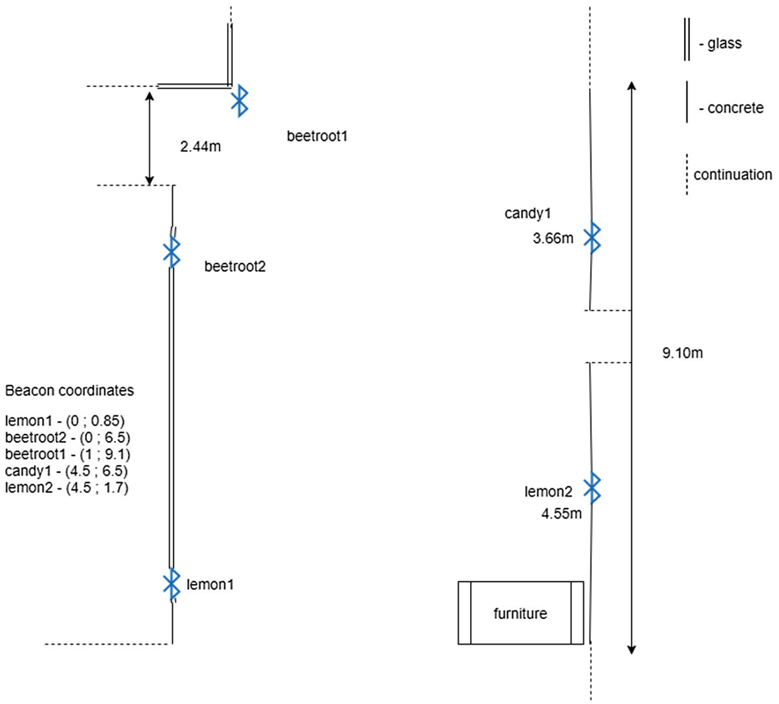

Fig. 2. Setup overview (Source: Fraunhofer Italia)

Table 1. Beacon accuracy measurements

Position #	Estimated location (X ; Y)	Actual location (X ; Y)
Position 1	(0.8 ; 3.8)	(1.5; 3.7)
Position 2	(1. 97 ; 6.6)	(0.3 ; 6 8)
Position 3	(3.03 ; 8.26)	(1.2 ; 8.2)
Position 4	(1.3 ; 9.4)	(1.2 ; 8.2)
Position 5	(4.1 ; 4.7)	(4.3 ; 4.7)
Position 6	(3.5 ; 8.6)	(4.3 ; 9.2)
Position 7	(2.2 ; 5.9)	(0.5 ; 7)
Position 8	(4.20 ; 0.27)	(3.8 ; 0.45)
Position 9	(0.24 ; 1.61)	(0.8 ; 2.2)
Position 10	(2.42 ; 4.57)	(2.17 ; 3.2)
Position 11	(1.9 ; 4.6)	(2.5 ; 8.3)
Position 12	(1.6 ; 4.9)	(2.7 ; 4.7)
Position 13	(1.5 ; 1.7)	(1.2 ; 1.6)
Position 14	(4.1 ; 3 4)	(0.9 ; 4.7)
Position 15	(1.3 ; 6.0)	(2.9 ; 6.6)

displayed or not. The whole system works around placing the virtual camera in the same position as the device camera. The "Location Listener" plugin reports the user initial location to the virtual camera so that it aligns itself and displays the 3D building components the user is looking at. By using the motion tracking capabilities of Tango, the device is able to track the user movement, so that the cameras always stay aligned.

Exporting BIM Data

The 3D model is not sufficient to provide the user with all the necessary information. Using a custom-made plugin for Revit®, the ACCEPT plugin[1], parameter information about every component is extracted in an XML format. This file contains the relevant information about the building component (e.g. height or width), related with an ID to the model-object. The script "Cliccable" allows each component of the model to be interacted with and permit, through a double click, to display this information.

```
selectedObject = hit.transform.gameObject; //the hit object
hitID = script.getComponentID(selectedObject); //get the id of
the selected component
component = script.getCompon(hitID); //retrieve the component
hitName = component.getGameObject().name;//BIM name
h = component.getHeight(); //geometry info
w = component.getWidth();
idField.GetComponent<Text>().text = compo-
nent.getID().ToString(); //update the GUI
nameField.GetComponent<Text>().text = hitName;
```

[Bridging 3D view with BIM information using the "Cliccable" script]

Through the export of a gbXML file from Revit®, it is also possible to capture information about areas of the project. An area is a subdivision of space within a building model. From this file it is possible to extract the bounding coordinates of all areas, therefore to be able to understand in which area the user is currently located. This allows the app to provide contextualized tasks that are linked to building components and specific locations on site. That means, the worker can quickly retrieve information about installation procedures, technical data, drawings, and quality checklists.

6 Results

The achieved result consists of a prototype application, which provides workers with relevant real-time information based both on the BIM model and on the user current position in the building. Users can perform the following actions (Table 2).

In this case, context-awareness, is achieved with respect to two dimensions: location and time. The Fig. 3. shows a demonstrative utilization of the application in the Fraunhofer offices, when they were still a construction site.

[1] Developed in the H2020 ACCEPT project, it is a BIM 4D plug-in to match BIM metadata data and MS-Project® scheduling and to import to the ACCEPT platform, in order to enable a more reliable construction scheduling and controlling.

Table 2. Functionalities of the AR4C application

Functionality	Description
Navigate 3D model	The worker navigates the 3D model in the application by walking in the real environment
Visualize element information	Allows the user to touch every element in the 3D model, and to extract information from that element
Read geometry information	The user can visualize a technical summary of a given component
Filter 3D Model	The user can enable and disable different levels of the 3D model
Consult task list	The user can consult a list of tasks currently available
Upload/Read note	Allows the worker to type/read a note related to a selected component and to upload/download it to/from the shared database by touching a button

Fig. 3. Using the AR4C prototype application.

7 Conclusions

In this research paper a platform for the integration of Augmented Reality and BIM was discussed. Usually, users adopt BIM for 2D and 3D visualization without exploiting full potentials of BIM approach and software. Moreover, Mixed Reality technologies have increasingly gained importance within the Construction Industry. The reason is given by their capability to manage different levels of reality perception. These can be combined with an efficient management of context-aware information and this combination could solve some of the most peculiar issues of the CI, namely communication and information flow management issues.

Considering these assumptions, it is clear that the implementation of innovative technologies as the AR4Construction platform, will be crucial in order to support the CI for the integral cooperation of all stakeholders in construction projects for the general increasing of productivity. Future developments might be to apply this application to a real construction site, in order to quantify its real potentiality. Furthermore, such system represents a stable starting point on top of which further functionalities can be built as extensions.

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