DIGITAL TOOLS FOR THE CONSTRUCTION SITE. A CASE STUDY: ACCEPT PROJECT

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Abstract: The construction industry is one of the most inefficient and fragmented sectors, if compared to other industries. Construction projects often encounter problems related to the mismatch between the expected and actual building performance. This mismatch is mainly caused by construction errors, which are generated by the wrong application of materials/components, poor collaboration between different stakeholders as well as by a lack of knowledge and skills of workers. The main objective of the ACCEPT project is to overcome these problems by developing digital tools that use highly innovative technologies able to support the following users: site managers, master builders and workers on construction sites. The ACCEPT system allows users to manage construction works according to lean principles and ensures the building quality and knowledge transfer in real-time to a specific user. The ACCEPT system consists of three main applications that run on

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smart glasses, mobile devices and PC. The main goal of this research paper is to describe the concept of the ACCEPT system.

**Keywords:** Digital Tools, Lean Construction, Quality Assurance, Augmented Reality, BIM.

1 INTRODUCTION

The construction industry (CI) is lagging behind other industries in implementing new Information and communications technologies (ICTs) to improve conventional processes and quality of construction works (Brandon et al 2008). The CI is still one of the most inefficient and fragmented sectors with lower productivity index, if compared to the manufacturing industry (World Economic Forum 2016). In other industries, ICTs have been successfully implemented thanks to several drivers that aim at modernizing obsolete approaches and processes. One of these drivers is the 4th industrial revolution, a trend called Industry 4.0 (European Parliament’s Committee on Industry, Research and Energy 2016). In addition, the CI has to face this challenge in order to keep pace with ongoing transformation at the global level. Although, the CI slowly adopts new process and ICT innovations, a legislation driver at European level boosts the digital revolution to initiate the modernization of this industry. In 2014, the European Parliament recommended to modernize the European public procurement law by encouraging the use of computer-based methods such as Building Information Modelling (BIM) for the public founded construction contracts and tendering (EUPPD 2014). According to the European Commission (2016), the industrial revolution is driven by new-generation information technologies such as the Internet of Things, cloud computing, big data and data analytics, robotics and 3D printing. As a result, many companies, such as Autodesk© and Google© are investing in the development of software for cloud-based project coordination as well as tools and mobile applications for Augmented Reality (AR).

In this context, the European Commission funded the ACCEPT (Assistant for Quality Check during Construction Execution Processes for Energy-efficient buildings) project through the Horizon 2020 Programme. The ACCEPT project is comprised of 11 partners around Europe: Ascora GmbH, AnswareTech s.l., Cype Soft s.l., EPITESSERA Architects, University of Liege – iD’s with LUCID-ULg research laboratory, Ingleton Wood LLP, Ferrovial Agroman, TIE Kinetix, Entreprises Jacques Delens s.a., Fraunhofer Italia Research s.c.a.r.l, Fraunhofer IBP. This project has started in January 2015 and it will last 36 months.

Besides the implementation of ICTs on the construction site, this project aims at achieving the followings key objectives:

- **Knowledge transfer:** Improve communication and transferring knowledge between the different stakeholders of the construction process by providing guidelines and information in real-time.
- **Project coordination:** Increasing the efficiency, reliability and productivity of a construction process by providing workflows and monitoring the construction progress based on lean construction principles.
- **Quality assurance:** Improving the energy and hygrothermal performance of buildings by providing quality assurance tools and self-inspection procedures during the construction process.
In order to reach these key objectives, the project consortium is developing the ACCEPT system with three client applications, which run on wearable device (smart glasses), mobile devices (tablet and smartphone) and PC. The promising technologies for reforming the CI, such as BIM and AR, will be also integrated in the ACCEPT system. According to Succar et al (2012), BIM has been changing the conventional design practices characterized by 2D digital drawings, document-based linear workflows and lack of interoperability into an object-based, model-based and network-based environment. Besides, the AR has a big potential to be implemented in the CI, since it provides significant advantages at different stages of construction projects through simulation, visualization and interaction. AR allows users to interact with both the real and the virtual objects by overlaying digital information, video, graphics and 3D objects onto real objects (Rankohi and Waugh 2013).

2 SOFTWARE ARCHITECTURE AND DEVELOPMENT

The ACCEPT System is envisioned as a distributed system with three end user contact points as well as a contact point for sensors. Figure 1 depicts the high-level architecture of the whole ACCEPT System. The four corners of the architecture are the four interaction points. The interaction with the end users will be done via the SiMaApp (mobile device), CoOpApp (smart glasses) and Dashboard (web/desktop). The Sensor Abstraction Framework (SAF) is the interaction point for the sensors/Internet of Things devices. In the centre of the architecture are distributed server applications, which will provide the different ACCEPT Services. The Visual Viki will provide assets and information for AR cloud-service in order to manage and interact with Extended Visual Annotations (EVA) and Executed Details Assets (EDA). The Service Market Place (SMP) will be the central point for ACCEPT’s Open Platform methodology. Further, Knowledge Information Storage (KIS) is a cloud storage, which will be used by all components of the distributed system. Finally, the Profile Nexus (PN) provides different services for the interaction with the four profiles: Project Profile, Quality Profile, Workflow Profile and User Profile. It provides the business logic that allows the interaction between profiles in an event-driven environment and will be a kind of Cyber Physical System to have a virtual representation of the different construction sites. In addition, PN will exchange information with BIM through Data Abstraction Layer. Every component will communicate through the Autonomous Messaging Framework (AMF).

![Figure 1: High-level architecture of the ACCEPT system](image)

Any software project always faces the communication problem between two distinct groups of stakeholders (e.g., different professional jargons), namely between subject domain experts and software development specialists due to the knowledge and language gap that intrinsically exist. Geneca (2011) reports that 75% of business and IT executives
anticipate their software projects will fail. At the same time, problems with communications appear in the top 10 reasons for projects failure in most of the studies. Being fully aware of this overwhelming statistics, the ACCEPT consortium had put in place the best practices that mitigated the risks and increased the chances of the overall success. First of all, the close collaboration and engagement of users were postulated. In order to overcome the communication gap it was decided to employ Domain Drive Design (DDD) methodology that provides as-domain ground for building a so-called ubiquitous language, i.e. the common language organically developed via cooperation of cross-disciplinary team members. The major outcome of the DDD process was a model expressed in the commonly understood language by team members and used for the communication among specialists of different background. Paper based prototypes and mocks greatly helped at the first stages of the project as a mean to develop the common language and the domain understanding. Scenarios were covered with extensive set of such prototypes and the early test groups of real users were invited to experience them. After that, the software development team went into the agile mode of running the software production. The main characteristics of the agile approach adopted by the technological partners were a use of iterative approach and constant communication with the users in order to maximise the business outcomes. The development was split into sprints where each cycle had to deliver a business value and can be demonstrated.

3 THREE CLIENT APPLICATIONS OF THE ACCEPT SYSTEM

The tangible results of the ACCEPT project are three client applications that run on mobile (smartphone and tablet), wearable devices (smart glasses) and PC, and are mainly used by site managers, master builders and workers directly on the constructions site.

3.1 SiMaApp: Application for site managers

SiMaApp aims at increasing scheduling reliability and productivity of the construction process as well as at supporting the quality check and reporting procedures on site. It is mainly addressed to site managers and foreman to allow the agile project coordination by construction progress tracking and day-to-day work management. This application runs on Android mobile devices. Tablet Project Tango© and smartphone Lenovo Phab 2 Pro© were chosen as test devices. These devices offer many advantages in AR application thanks to integrated sensors, inter alia, motion tracking, depth perception.

In SiMaApp users can display information related to the project data such as project drawings, construction details, component and material inventory obtained from BIM model. This application is linked to Visual Wiki that enables users to visualize EVA and EDA, inter alia, 3D models, videos, technical documents and sheets, etc. SiMaApp allows the coordination of the construction process according to lean principles by implementing approaches like Last Planner System® (LPS) and Location-based Management System (LBMS) (Kenley and Seppänen 2010). SiMaApp provides user with project scheduling, workflows for specific construction tasks and "To Do List" that assigns commitments to workers. SiMaApp supports also the quality check of construction works through standardized checklists that verify, for example, delivery status of construction components, installation of components, construction progress (Figure 2b). This application manages resources such as workers, crews and shared equipment involved in the construction project. Furthermore, SiMaApp enables the connection of sensors to actively collect data on the construction site and feed them to the ACCEPT system.
3.2 CoOpApp: Application for workers and foremen

CoOpApp is an application running on smart glasses within the ACCEPT ecosystem. It is able to display AR information in different data formats, e.g. texts, images, videos or 3D models. This app provides some features to create EVA and visualize EDA, both as AR data, and to take pictures and record video. All these features are available on smart glasses (Figure 3). The application is also compatible with any Android devices (smartphones, tablets and other smart glasses). CoOpApp is currently used on smart glasses Epson Moverio BT-200© for three reasons: availability in Europe, price and AR development possibilities. The idea of providing this technology to construction workers stems from the assumption that AR can be a solution for bridging the performance gap between as-planned and as-built, for improving communication between different stakeholders, for sharing document and for improving the quality control. The use of AR could become essential for control and validation processes on site. Visual Wiki is associated to this application with the ability to link information to a real world object. Pictures, videos, technical documents or virtual notes can be attached to a specific place. Thanks to this spatial link, the construction worker accesses directly to the right information at the right place. Finally, the application also allows a construction worker to share instantly what he sees with his supervisor. Those functionalities are powerful tools to avoid misunderstandings between stakeholders.

3.3 Dashboard: Application to monitor building and construction process quality

The Dashboard is a web client application developed in DART© and Polymer©. It uses the responsive design guidelines (Marcotte 2010), which allow web interfaces to adapt to the screen size of its devices. The application is designed for PC but also for tablets and smartphones. Dashboard collects information from multiple sources (sensors, checklists and workflows) to synthesize and visualize quality-related metrics and issues. In fact, Dashboard communicates with the Quality Profile in PN to retrieve data from different domains that the user wants to display. One of the key approaches while designing
Dashboard was to organize the application in a way to capture the user’s attention immediately on data that are more relevant to him/her and on issues met on a construction site.

According to the Fraunhofer IBP (Institut für Bauforschung e. V. 2015) two main factors related to the worsening of the final building quality are always present on construction sites: humidity issues and human errors. In relation to these problems, Dashboard offers two solutions. The first solution is an integration of the communication system between outside and inside sensors to control climate conditions (temperature and humidity) on the construction site as well as between measurements of surface temperature and humidity on materials, where further construction works should be undertaken (Figure 4a). During the construction, many works can be only done on a dried surface (e.g., screed laying). The site manager can retrieved from Dashboard information on estimated drying time of a material in order to update properly the work scheduling.

The second solution is an integration of questionnaires related to the specific quality issues (Figure 4b). Information collected by the questionnaire can be used to assist and document the construction works and to control their quality aspects. In Dashboard can be visualized a list of templates and answers as well as groups of warnings generated from the data processing included in the questionnaire templates.

4 PILOT GROUPS

All three-client applications will be tested and validated in three Pilot Groups through the pilot program applied to real pilot projects (construction sites). In pilot projects, BIM technology is adopted. The pilot program is based on the key functionalities derived from the Use Cases which define what the ACCEPT system is looking to achieve. 119 functionalities were identified and collected into 20 groups, which form the basis of pilot plans. Figure 5 shows the approach adopted in Pilot Groups. This approach will allow the flexibility to modify envisioned functionality when feedback is obtained, to include a new functionality or to drop functions without any benefits. These 20 pilot plans fit into three Pilot Groups, which are located in four different European countries. The Pilot Groups are split into two pilot stages. The first pilot stage focuses on qualitative feedback through an iterative process in order to improve the developing prototype of the ACCEPT system. Validation is achieved through the second pilot stage in the second pilot group with advanced prototypes where qualitative data will be tested against control processes (construction site without the ACCEPT system) in order to prove the concept and quantify the effectiveness of the ACCEPT system.
The first Pilot Group mainly focuses on the use of CoOpApp functionalities. This Pilot Group will be carried out in Madrid (Spain) and in Brussels (Belgium). This Pilot Group will test functionalities, inter alia, interactive AR notes, management of documents in AR, communication between different stakeholders, overlay of BIM model in AR and defect profile to identify a possible mismatch between actual building and as-planned model. Ferrovial Agroman chose the construction site of the residential complex - VIT BOX with 120 apartments in the northern part of Madrid as a pilot site. The second pilot site is located in Brussels and it is a highly energy-efficient and one of the most important project currently being constructed by Entreprises Jacques Delens. It represents 19,000 m² of housing and facilities, almost half of them fulfil the passive house standard.

The second Pilot Group addresses SiMaApp functionalities in particular and it will take place in a rural small residential construction site with a local contractor and with the assistance of a local housing association (Broadland Housing Group). Ingleton Wood will lead the pilot site and will coordinate functionality testing related to the project coordination, task assignment and resource management.

The third pilot group mainly focuses on the use of Dashboard functionalities and it is located in Nicosia, Cyprus. EPITESSERA Architects will lead the implementation of this Pilot Group in cooperation with a local contractor. This is likely to be a residential or educational building. Functionalities related to the quality assurance, delivery and inventory of materials, interaction with BIM Model and use of Dashboard will be tested.

5 CONCLUSIONS

Considering that the CI is lagging behind other industries in implementing digital technologies, the ACCEPT project aims at boosting the implementation of information technologies in the CI. Within this project, three applications are developed for smart glasses, mobile devices and PC and are mainly addressed to site managers, foremen, master builders and workers. The innovative aspects of this project result in the development of digital tools for the improvement of building quality, construction process and real-time knowledge transfer. The prototype of the ACCEPT system is under development and its basic functionalities are currently tested on pilot projects (first stage). At this stage, the qualitative feedback is collected in order to improve the developing prototype. At the beginning of 2017, advanced functionalities of each application will be developed. In SiMaApp, a project scheduling will be implemented according to LPS and LBMS. Features to detect automatically mismatches between BIM model and actual building, will be integrated in CoOpApp. Dashboard will focus on the integration of checklists within a workflow of construction tasks and on the integration of algorithm to estimate drying time for materials. In the middle of 2017, all advanced functionalities will be tested and validated in the second stage of the pilot sites.
6 ACKNOWLEDGMENTS

The authors would like to thank the European Commission for their funding of the ACCEPT project within the Horizon 2020 Framework Programme (Grant Agreement No. 636895). The authors gratefully acknowledge the contributions of the other partners from the consortium: Jesús Martínez and Tonny Velin from Answartech; Pablo Gilabert from Cype Soft; Elena Parouti from EPITESSERA Architects; Pierre Leclercq, Hatem Béjar and Vincent Delfosse from LUCID-ULg; Edward Gooden, Greg Day and Kim Kerrigan from Ingleton Wood LLP; Laura Tordera, Olga Gómez and Eduardo Sanz from Ferrovial Agroman; Peter Leo Merz from TIE Nederland; Arnaud Dawans from Entreprises Jacques Delens; Andreas Kaufmann from Fraunhofer IBP.

7 REFERENCES


