A BIM AND AR BASED PLATFORM FOR MANAGING NON-CONFORMANCES

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ABSTRACT: *Defects and errors are common and occur repeatedly during construction projects. An effective management of non conformances is vital for a streamlined and efficient production progress. Large quantities of data and information are produced, which can be lost or misinterpreted. Several defect managing systems have been developed to facilitate measuring and correcting defects. However, few focus on data and information gathering and sharing, as well as providing an efficient communication tool for teams on site. Building Information Modeling (BIM) has proven to improve communication and information sharing. The lack of platforms that integrate BIM in the communication processes used on site is hindering the full exploitation of its potential in improving communication. The overarching aim of this research is to develop a unified real-time communication platform capable of providing richer information for the decision making in the non conformances management process. This study lays out the conceptual framework for the communication platform "C-BIM-thru-AR" (Communicating BIM through Augmented Reality). This platform integrates BIM models into the communication channels used on-site and offsite via Augmented Reality (AR) systems. To develop the "C-BIM-thru-AR", first the systems functional requirements had to be established. To accomplish this, the Integrated Definition for Function Modeling (IDEF0) technique was used to create as-is maps to analyze processes included in production management and establish functional requirements. With the functional requirements gathered and by applying a system thinking approach, the platforms framework and network architecture were developed. The proposed platform aims at enhancing the management and quality of all the information produced from the management of non conformances, ultimately improving the processes productivity. In future studies, the proposed platform could be exploited in the management of subcontractors' performance which could be stored automatically in the "C-BIM-thru-AR" platform.*

KEYWORDS: *Building Information Modeling; Augmented Reality; Unified Communication Platform; Communication; Information Sharing*

1. INTRODUCTION

The unique and fragmented nature of the Architecture, Engineering and Construction (AEC) sector is well known and documented (Isikdag and Underwood, 2010). The issues raised from this fragmentation are also well known: low productivity and poor quality (Koskela, 1992). These issues make quality control one of the major concerns, for construction professionals, besides schedule and cost overruns. Studies show that defect related rework is considered a non-value activity responsible for 12.4% of construction cost and affects the industries productivity (Josephson *et al.*, 2002). Quality systems have been implemented in construction companies to better handle the management of non-conformances. However, the increasing complexity of construction processes, the increased paperwork and administrative tasks, and the additional costs experienced by construction companies when implementing quality systems' that fulfill the ISO 9001 requisites, are limiting the adoption of this norm by the construction industry when compared with other industries (Tang *et al.*, 2005). In addition, construction staff's natural reluctance towards paperwork and administrative tasks has decreased the acceptance of ISO 9001 compliant quality management systems.

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Some systems have been developed to handle defects occurred during construction (Park, 2012; Kim, 2008; Yu, 2007; Wang, 2008). However, the growing complexity of production management processes and the extensive array of specialists involved and their growing geographic dispersion, make information gathering and sharing a great effort managing the information produced between onsite and offsite personnel is yet to be addressed.

Building Information Modeling (BIM) has proven its benefits as a tool capable of enhancing communication and collaboration in construction (Sacks *et al*., 2010). In contrast to the primary and traditional communication channels used on site, based on two dimensional (2D) drawings and other paper based documents, BIM can support and provide process visualization of construction projects (Chelson, 2010). Moreover, BIM offers extended visualization features capable of reducing project process related problems, including quality defects (McGraw-Hill, 2008). However, issues on how BIM can surpass design to real-time on site construction still persist (Wang and Love, 2012), forcing BIM to be mainly used as a representation and simulation tool (McGraw-Hill, 2008).

In order to fill these gaps, this study proposes the integration of BIM models in the communication channels used on site through the use of augmented reality (AR) systems. To achieve this, a conceptual communication platform, has been developed to allow onsite and offsite construction teams to communicate and exchange information effectively. This relies on BIM and AR, where BIM models provide a tool to enhance the performance of informational tasks executed on site, and AR systems support the gathering and storage of information from the construction site into a single BIM model. The aim is to provide an effective tool, capable of monitoring quality control and enabling an effective interaction and real time data sharing, independent of user's geographical location.

2. LITERATURE REVIEW

2.1 Traditional Management of non conformances

The construction industry is characterized as information-intensive, where creating and sharing information is a cumbersome process. Despite all the research undertaken in identifying better methods for information sharing, it is still a time consuming activity. Generally, time is wasted on locating appropriate information or providing redundant information. This can be explained by the industries reluctance in changing the primary and traditional communication channels, based on 2D drawings and paper based documents and graphics, despite many researchers claiming that these channels are insufficient to guarantee a suitable communication, thus hindering productivity (Chelson, 2010; Sacks *et al*., 2010).

Similarly to other construction processes, managing non conformances also relies on traditional communication channels to record and share information. Traditionally, defected works are detected and recorded on 2D drawings or other paper based documents. The gathered data is then delivered to the site office, where it is rearranged and transposed into standard documents or into a computer system. This transition can result in data loss or misinterpretation. In addition, the data is often gathered, recorded and transformed into information by different individuals, with different roles and backgrounds. This harbors significant potential for misinterpretations (Golparvar-Fard, 2009). Moreover, data is often omitted or miswritten when converted (Park, 2012). Finally, work orders are issued based on this information and the necessary work is carried out. Often enough, this information needs to be transmitted to other stakeholders down the production line, such as subcontractors and suppliers. This is yet another step where the quality of the information transmitted can be worsened. This can result in ineffective rework which fails to eliminate the non-conformance detected.

Quality management plays an essential role in the construction industry (Wang, 2008). Despite modern quality practices not being able to guarantee a flawless product or service, their implementation in non-conformance management processes brings several benefits to the construction industry (INGAA, 2013). The same report states that these benefits include: Process improvement and a factual approach to decision making; Enhanced stakeholder satisfaction; increased efficiency; better planning; Continuous improvement; Improved Employee Morale; Improved control over documentation (INGAA, 2013). Besides the benefits that quality systems bring, they are responsible for assuring that the ISO 9001 requisites are fulfilled. In fact, implementing a system for managing non conformances is one of the major requisites prescribed by the norm. Thus, this is a particularly relevant issue for companies that aim at obtaining and maintaining ISO9001 certification.

Several systems have been developed to manage non conformances. Park (2012) classifies them depending on their approach as reactive or proactive. Systems including RFID technology (Wang, 2008), personal data assistants

– PDA's (Kim *et al*., 2008) and laser scanners (Yu, 2007) work reactively after non conformances occur. On the other hand, systems including some form of augmented reality system (Park, 2012) work proactively in managing non conformances before they occur, by continuous monitoring and early stage detection.

2.2 BIM – A tool for onsite communication

In contrast with the traditional 2D and paper based communication channels, BIM supports and provides the visualization of the project and construction processes. The development of 3D visualization through precise BIM models enhances the visualization potential of the physical and functional means of a facility, representing a great advantage for the stakeholders (Chelson, 2010). Thus, BIM can provide the necessary means to alter the communication dynamics encountered on site. BIM can aid construction professionals by simulating the future environment of a building, thus allowing the identification of possible project or production errors (McGraw-Hill, 2008). According to Sacks *et al.* (2010), communicating the project intentions effectively is one of the key functionalities of BIM, along with providing the opportunity to transmit information in dynamic views. These benefits can directly improve communication, making production meetings more effective and efficient (Sacks *et al.*, 2010). In addition, they pave the way for information sharing tools and for the enhancement of the communicational channels between production managers and onsite teams.

2.3 AR – Bridging the Visualization Gap

Froese (2010) describes the three technological eras witnessed in construction. Wang and Love (2012) mention a fourth era, where digital project information (BIM models), generated prior to construction, is brought to the construction sites. AR is the technology envisaged to bridge the visualization gap between office and onsite environments, through the visualization of digital information in the physical context of each construction activity or task. Further in their research, Wang and Love (2012) sustain that the visualization of BIM models on the construction site can improve the industry standards in the following key areas: interdependency; linking digital (paper) to physical; synchronization of mental models for communication; project control, monitoring and feedback (as built vs. as planned); material flow tracking and management in procurement; bridging the visualization gap from design to production; site plan and storage of materials.

Recent studies have identified AR application areas in Construction. Production management is one of the areas that can potentially benefit from AR systems. In particular, the informational tasks performed onsite have been investigated and the visualization opportunities existing in the use of this technology discussed (Shin and Dunston, 2008). The same study demonstrates how activities performed on site can largely benefit from the visualization of virtual models through AR applications. Activities related to planning and supervising both include intense information tasks like coordination, strategy, supervision and commenting, where all of them can benefit from the potentials of AR systems: digital information tagging and reliable 3D virtual models superimposed onto the real scene.

3. RESEARCH METHOD

The strategy used was based on a systems approach (Ramo and Clair, 1998), where construction processes adopted onsite are considered as part of a system - Production Management. The objectives consisted of modeling the entire operation included in the non conformances management process and then define the functional requirements for the "C-BIM-thru-AR" platform. In order to achieve this, the research was divided into two phases:

Phase 1: Process Analysis – Case Study

A case study was performed in order to model all operations behind the "non conformances management" process included in the production management process of a Portuguese Construction SME whose production is centered in building. The functional requirements for a conceptual communication platform were captured using the IDEF0 modeling technique. *As-is* maps were created towards analyzing processes and establish functional requirements.

Phase 2: Process Modeling – "C-BIM-thru-AR" framework development

Based on the findings and insights obtained through the literature review and the functional requirements captured in phase 1, the "C-BIM-thru-AR" systems framework and network architecture were developed by adopting a systems thinking approach, where the informational tasks that compose the management of non conformances process are integrated into BIM models. Enhanced visualization is then achieved by adding the information generated during this process to the virtual models utilized, which are superimposed to the actual physical context though an AR system.

4. PROCESS ANALYSIS – CASE STUDY

Using the IDEF0 modeling technique, all the activities and relations between them, included in a specific process of production management, “Managing non conformances” were modeled. The chosen process for the current study is one of the most important processes included in production management of any type of construction project.

4.1 Modeling the Production Process

The chosen process for modeling involves all activities included in the following sub processes: controlling and supervising production; resolving non conformances; hand over building. The process was decomposed into higher levels of details (A0, A1, …, A21, …, A311, …, A422), in order to capture all the interconnected relations among the various processes.

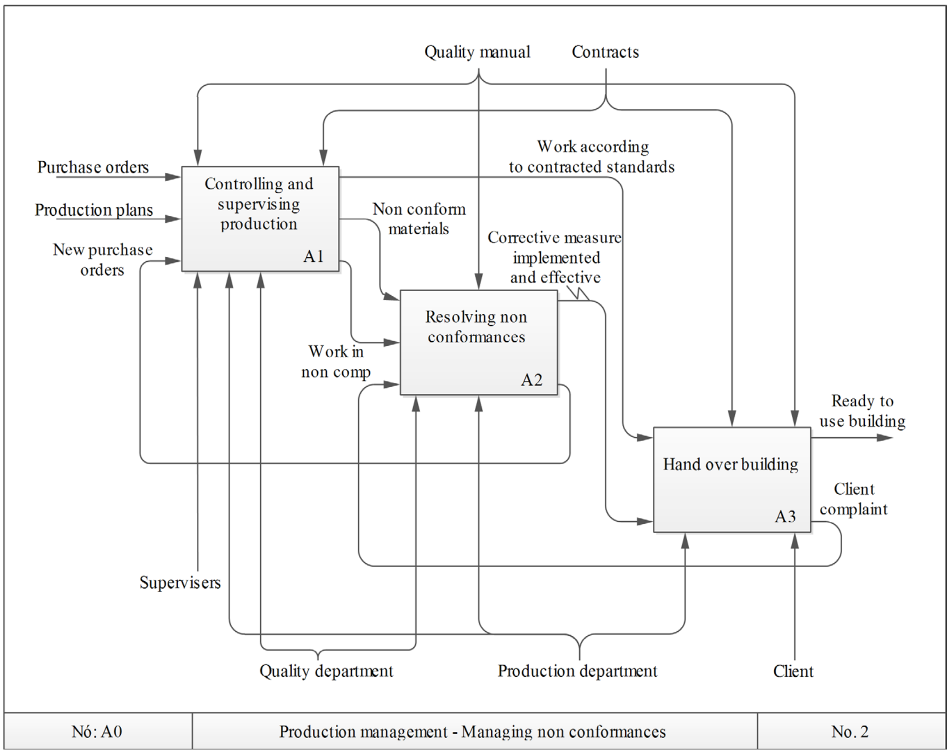

Fig. 1: Production management process – managing non conformances

4.2 Decomposing the production process

The main sub-processes and activities that form the “Production management process – managing non conformances” are shown in Fig. 1. As shown in the diagram, there are three main activities in the mentioned process, with information exchange and interactions between them also being identified. In order to reach the interactions between teams and workers onsite and capture information exchange between them, it was necessary to decompose each of the represented activities in two levels of detail. The analysis was then centered in ascertaining the main needs of each activity concerning documents, protocols, tools and constrains. It was also possible to acquire knowledge about the strong and weak points of the procedures of each activity.

4.3 Establishing Functional Requirements

At the end of the process analysis and by the conclusions taken from the different interviews, the functional requirements for a communication application for production management were identified. Comparing the identified requirements and the current process deficiencies, it was possible to develop a framework for the C-BIM-thru-AR application. These requirements were first grouped into two sections that represent the main primary needs of the production management process: sharing data, represented in Fig. 2 and gathering data, represented in Fig. 3. With the IDEF0 *as-is* maps the authors were able to identify the deficiencies of the actual process and, by crossing them with the needs gathered from the different staff and stakeholders interviews, the functional requirements for a communication application for the managing non conformances process were clearly identified.

In each section, functional requirements were identified that could fulfill the needs of the studied process. In order to respond to sharing data needs, the proposed application has to provide easy access and correct standardized

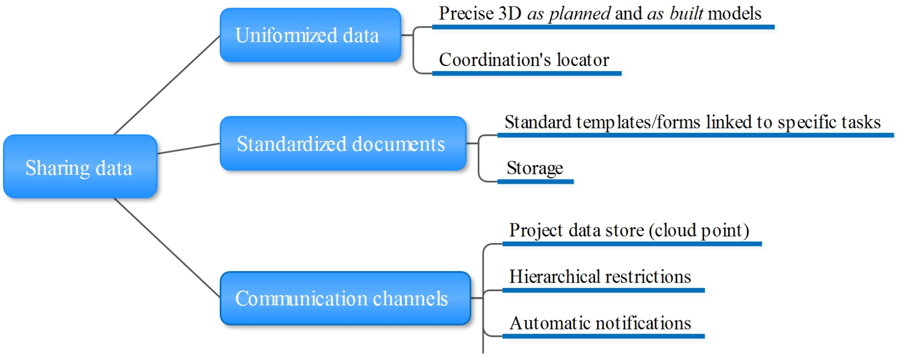

Fig. 2: C-BIM-thru-AR functional requirements – Sharing data requirements

documents, uniformed data which is not subject to misinterpretations, , and effective communication channels.

Fig. 2 illustrates the application's tools associated to each functional requirement: precise 3D models, coordination's locator, standard templates/forms, storage, sharing information cloud point, automatic notifications and open class formats. The functional requirements for the gathering data section were divided into two distinct sub-sections: Onsite data capturing and office data capture. Both locations share the same needs related to gathering data. However, due to their physical nature differences, each of them has specific functional requirements, as illustrated in Fig. 3.

5. COMMUNICATING BIM THROUGH AUGMENTED REALITY, C-BIM THRU AR

A system framework (Fig. 4) and its associated network architecture (Fig. 5) have been developed in order to create a bidirectional flow of information between construction job sites and different stakeholder's workspaces. In this context, the C-BIM-thru-AR conceptual platform focuses on the visualization and modification of project data and information sharing during a specific production management process – Non conformances management. Design and calculations processes were not considered at this stage. Therefore, this concept is intended for management purposes throughout the construction phase of any given project. It is suited for all stakeholders involved in the production management process, i.e. superintendents, site managers, project managers, production and quality managers. The C-BIM-thru-AR platform consists of two interdependent modules: one for construction site use (C-BIM supervisor), another for office use (C-BIM manager). These modules are available to the users as intelligent interfaces which are differentiated by their functionalities, display devices, tracking devices, AR systems for virtual models visualization and permissions to access project information by limiting the number of databases connected to each tool. Their functionalities will be described in the next section.

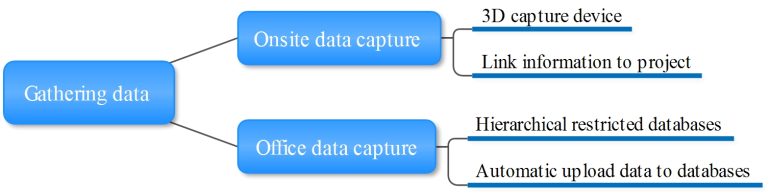

Fig. 3: C-BIM-thru-AR functional requirements – Gathering data requirements

The C-BIM supervisor main functionalities are supervising and commenting. The display devices proposed include a tablet pc for image displaying and a specialized digital camera for 3D reconstructing. This module

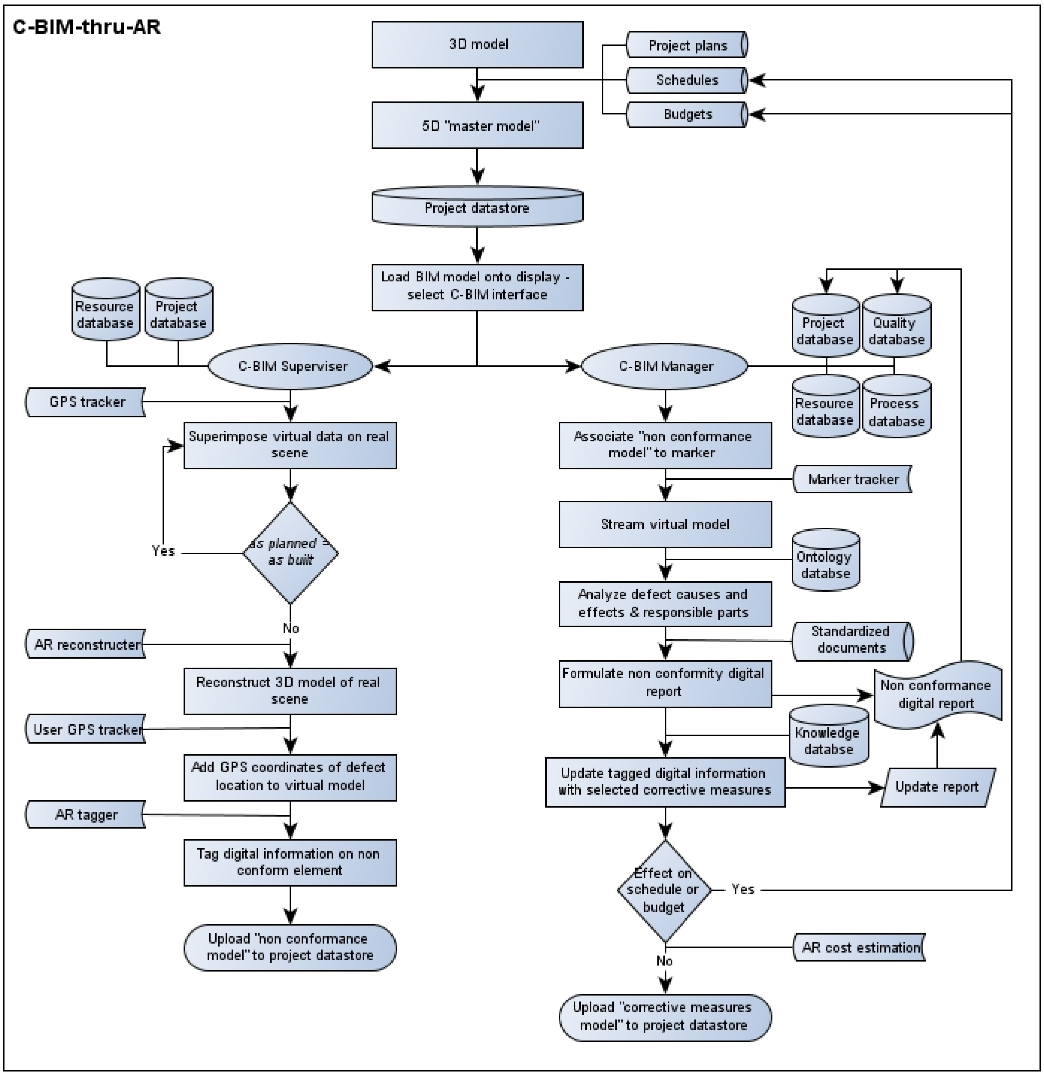

Fig. 4: Conceptual system framework for enhanced onsite communication

feature works similarly to the prototype developed by TNO, Netherlands Organization for Applied Scientific Research, for 3D model reconstructing with the objective of securing crime scenes (TNO, 2012). The module uses a sensor based tracking system (GPS), incorporated in the tablet pc to track the user's position and an attached electronic compass, to track the user's orientation. An AR system provides augmented reality visualization, interaction with the user and information capturing, where the viewing projection is provided by the C-BIM-manager server. The necessary technological solution already exists. It was developed by VTT, Technical Research Center of Finland and applied to its OnSitePlayer module, i.e., the software application AR4BC (Woodward *et al*. 2010). In terms of linked databases, it is limited to project and resource databases.

The C-BIM manager's main feature is the possibility of managing and modifying project information and documentation based on the information gathered on the construction site, and instantly updating new information through its standardized document database. Each available document type is linked to a specific task, i.e., as soon as the site manager wants to report a non conformance, the system automatically opens a non conformance standard document. Its display devices are either portable pcs or desktop pcs with powerful graphic processors, equipped with a digital camera. It uses an optical based tracker (markers) to track the virtual models and has live stream functionality. The visual projection of the virtual models is also done by an AR system. In this module the viewing projection system will be similar to ArToolKit, by the Human Interface Technology Laboratory (HitLab) and ARToolworks, Inc (Kato, 2003). In addition, by connecting the AR system to specific databases, it provides the user with an automatic cost generator option, used when adding new construction elements to the project model. This functionality basically works in a similar way to the construction management simulation utilized in Real Person Games. A list of construction materials from the company's resource database is made available to the user through the C-BIM manager interface, together with a picture of the resource and the associated costs. The user then chooses the desired material and its quantity, and cost estimation is automatically added to any report or model updates. Concerning physical workspace, the C-BIM manager designed to be used in distinct geographical and functional areas, such as onsite and offsite offices, with differentiated access to the databases available, according to the role of the user.

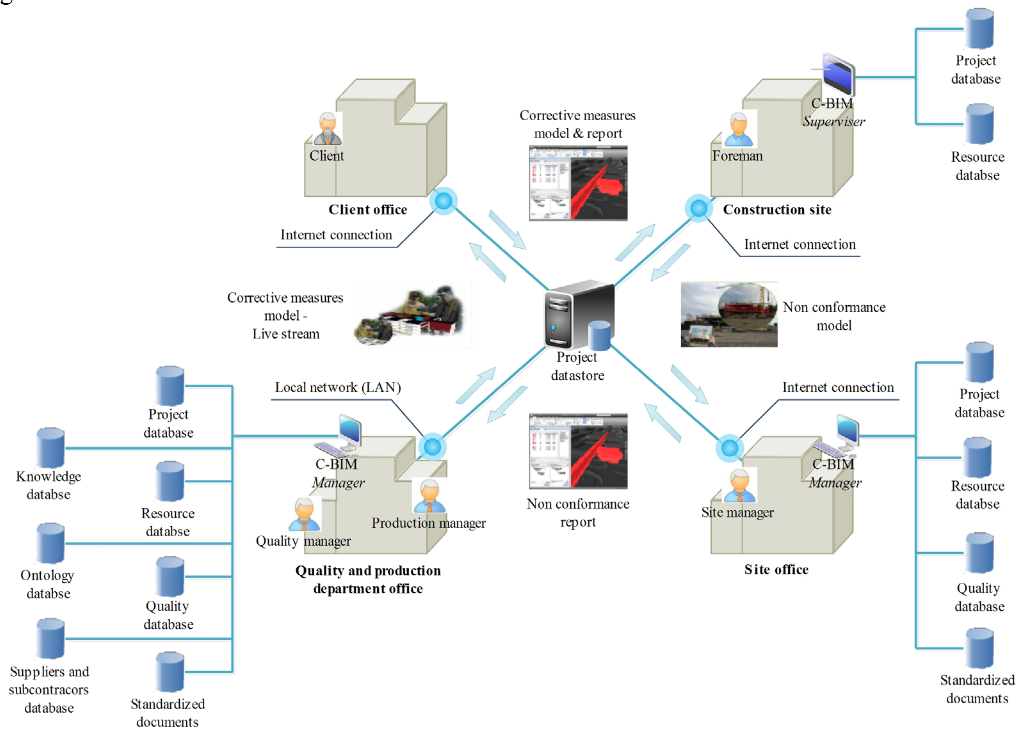

Fig. 5: Conceptual network architecture for online information sharing

5.1 System's conceptual framework

Following the functional requirements established in the previous chapter, an efficient tool to enhance and improve information sharing and real time communication in managing non conformances should focus on shared data immune to misinterpretations and an informational and communicational tool, both for onsite and offsite use, capable of gathering data in real time. Fig. 4 shows the system's main functionalities and processes. The system uses roll based interfaces in order to facilitate its use and mainly to create a hierarchical access to the project information. As mentioned, two different interfaces have been conceptually developed. The interfaces were developed having in mind the possible optimization of the non conformances managing process and the user's role, workspace and professional needs.

"C-BIM supervisor" is exclusively for onsite use. By logging into the system through the supervising role, the interface superimposes 3D models (imported from the project data store) on to the real scene by an augmented reality system, combined with GPS tracker. This permits the user to compare *as planned* data with *as built* data. When the user detects any kind of defect, he freezes the image and initiates a 3D reconstruction of the defected element. With the commenting functionality, the user can accurately tag the defect coordinates on to the BIM model and add digital information about the defected element.

"C-BIM manager" is aimed for office use. By logging into the system through the onsite managing role and downloading the "non conformance model", the user can now access different databases. By associating the downloaded model to a marker, the user can project upon any surface in his or her present location, in order to have better perception of the defected element though spatial, interactive visualization. With the linked ontology and standard document databases, the user can accurately fill out a non conformance report. In the office managing role, the user has access to all the project related databases, live stream and cost automatic adjustment. Reports can be updated and visual information can be shared with the client and with the AR budget functionality, which is linked to the resource database. He or she can then add constructive elements to the "corrective measures model" and estimate the respective rework cost. The database should include simple and composed costs.

5.2 System's network architecture

Fig. 5 shows the interconnections between different stakeholder's workspaces and the cycle for the non conformance management process. The first stage of the proposed system focuses on project monitoring and supervising from the construction site perspective and tracking of the building elements production and quality. In the previous chapter the role of the "C-BIM supervisor" was described for this use. In the process of tracking the occurrence of non conformances and proceeding to their rework, various parties are involved. The onsite crew tracks and updates the status of the building elements. The information is transmitted from the "C-BIM supervisor" interface to the project data store and from there to the on-site office via "C-BIM manager". At this point the "non conformance model" consists of a virtual model tagged with digital information, with the non conformance location coordinates and with its 3D reconstructed model. The model is made available to the site manager, who uses it for detailed planning and for submitting accomplished work reports. The site managers analyses the need for rework. Using the *as planned* 3D models they become aware of impacts on the current planning schedule. A non conformance report is then formulated with "C-BIM-manager" standardized document database.

As soon as the site manager submits any type of report, production and quality managers are notified. The system's hierarchical restrictions allow these departments to access further databases, besides the interface layout and access privileges of the site managers. These restrictions are intended to keep the system light, functional and to reduce the complexity of the production management processes. From the user's point of view, the system's role restrictions limit access to the strictly necessary documents and databases for users to perform their activity in an effective way. By accessing all available databases, the production and quality managers are able to evaluate the causes of a non conformance and chose the most appropriate corrective measures, with the help of a knowledge data base that includes previous experiences in other projects. At this point the "corrective measures model" consists of a virtual model tagged with digital information, which includes the non conformance location coordinates, its 3D reconstructed model, the rework instructions and the cost estimation of the rework.

The cycle is ended by communicating the adopted corrective measures to the client and back do the construction site. The communication and information sharing, between off-site office and client, is guaranteed by the marker based AR viewing projection and live stream functionalities. The offsite office user projects the virtual model in the office, with its respective 3D reconstructed models, and interacts with the client through the live stream option. With this communication channel, the client can visualize the models and simultaneously observe the offsite office user's gestures and instructions. This provides the client with the opportunity to actively participate in the assurance of the project's quality standards, despite of his or hers current location. From the perspective of the onsite users, they are notified as soon as the "corrective measures model" is approved. From then on they can access rework instructions, annotated drawings and reports of the non conform element, all available in the project data store. Through a simple color code applied to the several reports the site manager is provided with a prioritized work list.

6. DISCUSSION

A significant number of software applications and different formats are used in *C-BIM-thru-AR* throughout the entire project. This anticipates interoperability issues, which will have to be dealt with before the proposed framework can be implemented. Interconnecting all different documents formats and databases and the proposed systems will be particularly challenging. An anticipated strategy for addressing these issues is the utilization of Industry Foundation Classes (IFC) formats by all software applications when processing their respective data and documents, thus allowing for a smooth incorporation into the proposed system interfaces. Another obstacle to overcome is the potential intellectual property issues arising from the fact that a number of different proprietary AR systems are considered in the framework of the proposed platform. It utilizes functionalities from four different AR applications: 3D reconstruct; digital information tag; visualization of virtual models, and automatic generation of costs. At the same time, the tracking technology considered (GPS) doesn't provide pin point accuracy and has issues in sub terrain structures. Hammad (2004) reviews several existing tracking technologies and their associated accuracies. This author states that hybrid systems can achieve desirable accuracies when using multiple measurements obtained from different sensors to compensate the shortcomings of each technology when used individually. A promising hybrid system for solving tracking issues consists of measuring position by differential GPS, and inertial tracking and orientation by a digital compass and tilt sensors. The integration of the measurements from different positioning techniques from the different sources involved can be obtained through the use of a *Kalman* filter, which also performs data homogenization and noise reduction. (Hammad *et al*., 2004; You and Neumann, 2001).In terms of potential benefits for production management, the proposed application can easily be adopted by construction companies due to its simple and user friendly interfaces. The users will need minimal training to rapidly master all the application's functionalities. The application was modeled considering functional requirements and the professional needs identified throughout the interviews performed for the case study. As a result, C-BIM-thru-AR provides better means for decision making, with its real time communication and information sharing capabilities – based on AR systems – thus increasing the stakeholders' awareness by continuously updating the jobsite's progress. In addition, stakeholders' satisfaction is enhanced since all information is kept in the project data store module, each user has permanent access to project information (original project and all its updates) according to role privileges, and virtual visits to the construction site are enabled to the stakeholders from any location. This feature is particularly interesting due to Construction's growing globalization. Besides, a continuous improvement of the construction companies' projects is also enabled, since past construction issues and defects are stored and easily accessed. Thus, it is possible to avoid recurrence of issues and defects. By providing a software tool for onsite use based on the projection of BIM models by AR systems linked to all relevant databases, a better documentation control and management is achieved, allowing the users to access any type of document in real time, regardless of their location.

The costs of implementing new ICT tools can also be seen as an obstacle, especially if a recent investment has been made by the stakeholders in other ICT tools. Comprehensive cost-benefit analyses will need to be carried out, taking into consideration the expected ROI of the previous investments and the expected benefit from the implementation of this system. This is particularly challenging, as it is difficult to quantify the benefits of enhanced communication and improvement in human, professional relationships onsite and the benefits that they bring about. Cost-benefit analyses of new ways of performing work are always challenging, as something known needs to be compared with something that will be. This is particularly felt in software projects. Another fundamental aspect that needs to be guaranteed is the adherence of the client to this platform and *modus operandi*. The fact that C-BIM-thru-AR does not require the client to acquire specific technology, other than conventional live stream applications, greatly facilitates this step, as the benefits brought about by this platform will be made available to the client without extra costs.

7. CONCLUSIONS

This paper first modeled the operations associated to the process of detection and resolution of non conformances, followed by the building production department of a Portuguese SME. Then, the "C-BIM-thru-AR" framework, its conceptual communication platform and network architecture were proposed. This study focused on the objective of transmitting accurate and consistent information from the construction site to different workspaces, thus increasing the production management means to face the unexpected issues that always arise during construction projects. Information exchange with third project participants, such as subcontractors and suppliers, is not yet considered. Future works should include imbedding subcontractors' and suppliers' performance assessments in the proposed system's database. This will enable a real time automatic update of the databases with information gathered in the work front and processed in the site office. Ultimately, concentrating all information exchange and communication channels used by all stakeholders and project participants into the C-BIM-thru-AR platform is sought, with the incorporation into the platform of an automatic workflow notification tool. This can be achieved by the development of new interfaces for every role included in construction projects.

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