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Real-Time Building Information Modeling (BIM) Synchronization Using Radio Frequency Identification Technology and Cloud Computing System

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Abstract

The online observation of a construction site and processes bears significant advantage to all business sector. BIM is the combination of a 3D model of the project and a project-planning program which improves the project planning model by up to 6D (Adding Time, Cost and Material Information dimensions to the model). RFID technology is an appropriate information synchronization tool between the real and virtual world of BIM. Also, the use of cloud storage and computing system would bring about outstanding data access capabilities to the constructors as well as other project participants.
The accurate prediction power that BIM brings to construction management and real-time status update, while utilizing the RFID technology, would greatly influence the efficiency of automated project management and post construction life-cycle maintenance. Meanwhile, cloud system will facilitate broad data transaction capabilities with the project. Hence, these integrations would enhance construction management by improving the data communication speed, real-time construction site control process and Human Resource Management as well. This paper introduces and evaluates a framework, which integrates Radio Frequency Identification (RFID) technology for real-time, mobile construction-site monitoring through a virtual model (BIM) and cloud data sharing as well as for processing activities. A case study has been carried out in the construction site of a new dormitory in Eastern Mediterranean University to examine different feasibilities and limitations of the framework.
Keywords: BIM, cloud computing, RFID technology, construction management

1- Introduction

Due to the dynamic characteristics of the construction industry, the operation planning management and resource management within a construction site are incredibly vital in improving the project in both time and cost efficiency. Time efficiency and waste elimination have great leverages in the construction industries relatively (Ren et al., 2007).

Building Information Modeling (BIM) is one of the tool that is being used more frequently in modern construction projects (Eastman et al, 2011). BIM is the most recent generation of the OOCAD (Object Oriented Computer Aided Design) that contains all the information about the objects which combine together to form a building structure (Howell and Batcheler, 2005).

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BIM facilitates the construction operation`s information flow in two segmented steps; this altogether would trigger the data flow within the information network of the project.

The first step is the component or property selection and the second step involves retrieval of the information of the corresponding element in the virtual model.

Currently, the first step is being done by manual navigation of the model (Meadati et al., 2010). The second step which involves transferring and interpreting the updated data into the BIM model, has recently been facilitated with cloud computing and the global data sharing system (Jardim-Goncalves and Grilo, 2010), in order to speed up the data flow within the construction project.

One of the common tools that the BIM users utilizes in order to update their virtual model, is barcode labeling of components and utilities as well as the linkage of real life components to their corresponding digital information, especially when the BIM models are facilitated by the cloud system. This is done by scanning the barcode labels one by one; the technicians can retrieve and edit the related information of the facility or component and all of these could be done by using the BIM/Cloud apps that are available which are capable of using barcode system(Eadie et al ,2013). However, regarding to Barenji (2013) barcode labeling has limitations surrounding its remote and real time status update of the BIM database.

Radio-frequency Identification (RFID) system uses tags attached to a component to be identified by the readers; the two-way radio transmitter-receivers called interrogators or readers sends signal to the tags, reads and edits the stored information on the tags, and finally, the readers generally transmit their observations to a computer system running RFID software or RFID middle ware (Barenji et al., 2013). The aim of this study is to utilize the BIM model as a construction management tool with an online updating system using the RFID and cloud system, in other to make its application more beneficial for construction management. This study will present an integrated construction monitoring system that uses RFID technology to update element`s status in the 3D BIM model and then distribute the information using the cloud system. The framework utilizes the RFID technology as a synchronization tool for BIM to aid the construction project`s processes i.e. during construction and in post-construction operations and facility management. Systematically, the implementation instruction of the framework, its applications and advantages will be discussed in this study.

2- Materials and methods

2-1- Background information about Building Information Modeling (BIM)

According to the National Building Information Modeling Standard (NBIMS) by National Institute of Building Sciences (NIBS) (Penttilä, 2006), Building Information Modeling (BIM) is a digital representation of the physical and functional characteristics of the facility. A BIM is a shared knowledge resource on information about a facility, forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to its demolition.BIM model works as a platform which operates by communicating with a complete and detailed construction information database; this allows the authorized positions to their accessible information and lets them input, extract, update and edit these digital data throughout the building lifecycle (Goedert and Meadati, 2008). Each construction project has four different segments in its life cycle. An illustration of this segmenting is shown in **Error! Reference source not found.**.

2-2- Cloud computing

The internet and developments in computer and mobile technologies has not only changed the lifestyles of humans but it has also shaped the business world (robot). The mannerism of paper based old business transactions are replaced with new smart devices including PCs, smart phones, and tablets. Although the history of computers and internet in the business spectrum isn't too long, today one cannot imagine a business day without utilizing these devices.

Cloud computing as an increasing technological trend, combines various known technologies through the power of internet. From the date this terminology was used until now, it has reshaped and continues to reshape the traditional IT process. Zhang et al., (2010) stated that the cloud computing technology has become possible thanks to the rapid advances in computing technologies such as processing and storage, as well as the success of the Internet.

Although there is still no exact definition for cloud computing, The Institute of Standards and Technology (NIST) defines cloud computing as *"a model enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction"*. In general terms, cloud computing refers to a cloud which comprises both delivered services over the Internet and sources of these services; for example, datacenters including hardware and systems software. The remote accessible hardware and software are actually what people call as the cloud (Adetunla et al., 2016). Cloud computing provides numerous advantages over the traditional services. Grossman (2012) stated the reason why cloud computing has become so popular is due to three topics: scale, simplicity and pricing.

Exploiting true capabilities and capacities of the cloud system would require an integrated, network-based collaborative BIM model instead of a collection of standalone files and documents. The integrated model would need *active BIM server* sector that enables the real-time collaboration of project participants that provides real-time access to the live BIM model for any stakeholders through software applications running on various mobile devices. Aforementioned, intensely active BIM server requires a multitenant software architecture in order to be able to scale up with the "cloud" and fully utilize its infinite data storage and computing capacity to provide the best return of investment (ROI) on the IT infra-structure(Varkonyi, 2011).

2-3- RFID Technology

The RFID system is a set of tags, readers with antennas and a software application that works as a middleware and a driver for a server computer. The tags are usually stationary and are connected to equipment or components. Each tag will have a unique ID which is recognizable to every member involved in the component`s supply chain (Barenji et al., 2014).

The main role of this system is to gather the information from the tags in real-time, even if the tags are not within the line-of-sight; this accomplished by sending radio waves to the tags (Barenji and Degirmenci, 2015). Readers can read and find tags that are within the range of detection of their antennas. **Error! Reference source not found.** is a simple and overall illustration of a typical RFID system.

RFID systems consist of hardware components which includes: tags, antennas, readers and host system while the software components is composed of the RFID system software, RFID middleware and application software. The sequence UML diagram proposed by author in the last work illustrated in the Figure 2.

3- Proposed framework

To structure the step by step demonstration of the framework`s implementation instruction, the construction processes has been divided into four segments, in the same manner it had been done in second chapter (BIM section **Error! Reference source not found.**). **Error! Reference source not found.** is an illustration of these four segments in sequence.

3-1- Project planning phase

At this stage, the site plan and the 3D model would clearly generate an understanding about the space limitations of the construction site. BIM model would aid the project planners to understand the space complexities and land regulation that exists in the project construction area; this will enable the project planners come up with the most optimum site and facility location plan. When this stage is reached, the decision makers should forecast with as much accuracy as possible, in other to plan towards making the construction operations to be acceptably sufficient.

Accordingly, this framework generally approaches the fundamental decision and finalizes it within this stage; moreover, the decisions about RFID tags and readers must also be finalized at this stage. These decisions should cover:

Tags:

- Which structure members are going to have RFID tags attached to them? (Columns, Beams, Door frames and etc.)
- All of the non-structural members in the building that are going to be tagged.
- When are the chosen components going to be tagged?

- What is the equipment tagging instruction?
- Whether the project will have HR tagging or not?
- Which tags are going to be passive and which one would be active?
- Which type of passive tag?
- Which type of active tag?

Readers:

- Will the project have any gate type reader? If so, where is it going to be located?
- Stationary readers' data filtering information for specified readings.
- How many portable readers are needed?
- What type of portable reader?
- Reading schedules and reading sequences of the tags by the portable readers.

The outcome of this phase`s decision will be two bottom layers of the framework as illustrated in **Error! Reference source not found.**.

3-2- Design phase

When the project reaches the design phase, all of the operational strategies are clear and so, the operation directors and engineers have to find the most optimized operational processes to carry out and initiate the project. Considering the RFID/BIM framework, all the fundamental actions are required to satisfy the decisions described in the previous section. At this stage, the whole system should be designed in both the software and hardware aspects, in order to get the project ready for the initiation of the construction. Initially, the design phase RFID/BIM operations will implement the planed strategies about tags and readers as well as create two layers above two previously mentioned layers of tags and readers; as a result, this would finalize the framework in four layers. . RFID implementations (according to decisions of the Planning Phase) are linked to the BIM model through smart software applications; and then, the upper layers (Smart software local applications and BIM model) are connected through cloud service which also needs to be prepared at this phase. **Error! Reference source not found.** illustrates four outcome layers of the planning and design phases.

At the end of this phase, the processes and implementations of the integrated framework of BIM/Cloud/RFID is ready for use. The modified BIM model and the customized software applications which handle the RFID technology will now be connected through the globally available services of the cloud system; hence, great amounts of observation capabilities has been provided for the owners and managers. Relatively, fast information flow capabilities will make project planning, operation management, inventory management and resource management greatly integrated and sufficient. Furthermore, the functionalities, processes and methodology of this framework during construction and post construction will be described in the following phases.

3-3- Construction phase

The main purpose of the design of this framework is this phase, due to the full capture of every aspects and capabilities of the framework. All the decisions that the management had made in planning phase as mentioned in related sections, were associated with an applicable strategic reasoning; This will proof useful as the capacities and functions of the framework in construction phase; at this stage, the framework`s related operations are of two segments i.e. the "**Error! Reference source not found.**" and "**Error! Reference source not found.**". The benefits, results and applications of implementing this framework during construction, will aid the project management in following criteria: (a)**Error! Reference source not found.**,(b)**Error! Reference source not found.**,(c)**Error! Reference source not found.**, (d)**Error! Reference source not found.**, and (e)**Error! Reference source not found.**.

3-4- Post-construction applications and benefits

After construction all of the RFID tags which were attached to building`s components, would remain attached and they are still readable by any type of reader, thus once again information about the components is going to be retrievable. The building would act as a group of smart objects which are linked to the building BIM 3D model, hence, it could have all the benefits provided by the BIM integration with additional enhancements associated with the RIFD integration and cloud system capabilities altogether. The framework`s additional benefits are described in this section under two perspectives i.e. (1) The Facility Manager and (2) Construction firm.

4- Case Study

Case study is a scaled examination of the RFID integration in BIM/Cloud system. The beauty of case study is that it demonstrates and examines the capabilities of this framework first in operations related to data retrieving and data editing done by portable readers.

In order to demonstrate these two scenarios a room in the Eastern Mediterranean University`s dormitory which is under construction has been chosen as the experimental area. An approximate BIM model of the room has been developed in Autodesk Revit Architecture 2012. Two software programs had been developed by C# Visual Studio .Net Framework; one for the portable device and the other for the stationary computer. The communication between these two software is developed based on XML (Barenji et al., 2016). RFID reader updated information to the first software and the RFID software updated information to the cloud by XML. The handheld tablet device with a built in RFID reader with internet connectivity capabilities was chosen as the portable reader in this case study. Also, the RFID antenna is located at the entrance of the room as the smart gateway in this case study. The antenna is connected to a reader which is located beside the laptop computer that is also located in the next room through the means of wiring. The computer contains the software program that is prepared for the stationary computer and this is connected to the internet. Ten different tags have been chosen for the experiment of which their ID codes where defined in the software programs. **Error! Reference source not found.**illustrates pictures of tags and tagged air-conditioning system as well as light switch; also, **Error! Reference source not found.** is a list of RFID tags' IDs and the component assigned to them.

In Revit, the BIM model of the room showcasing all of the components listed in **Error! Reference source not found.** has been defined and all the respective additional type parameters has been added to their identification parameters which will be used for the case study`s test scenarios. The first two tags represent tags that are going to be attached to the technicians doing the experiment. Additionally, the defined parameters and details of the parameters as well as details of defining them in the program are listed in **Error! Reference source not found.**.

There are three properties to be defined for each parameter as listed in **Error! Reference source not found.**. The discipline property of the parameter defines how it is going to be used in Revit i.e. either it is going to be used within the internal functions of Revit (structural or Electrical) or it is just going to be a common parameters for other uses. All of the parameters defined for the purpose of this case study are defined as common parameters. Type of the parameter is under the category of the input value. It defines the range and type that is allowable for the input value of the parameter (e.g. Text, Integer, Time, Yes/NO and etc.). All of the parameters in Revit are divided into different groups such as Dimensions, Structural, Graphical and Identity Data. Since the scenarios demonstrated in this case study are scaled version of the real application of the framework(i.e. with the aim of testing the RFID integration with the available BIM and cloud systems), the cloud system that is utilized in this case study is not a computing cloud system that has been specially designed for BIM like Autodesk 360; as a matter of fact, it is just a simple commercial cloud storage provider which would satisfy the aim and functions of this examinations. In the ideal situation, the cloud system can operate files related with BIM software programs. Consequently, the software programs that have been developed for this examination are design to perform within the aforementioned cloud network and to operate within the expectation of the case study and not the real-complete framework.

The aforementioned description could be considered as a scaled planning and design phase of the case study. Scenarios that to be explained are going to perform as examples of operations done during the construction phase of the project.

At this instance, a worker (a student) will pass through the chosen room with the portable reader. The aim is to find a specific component, edit one of its status parameters and then, the "Air Conditioning System" will be chosen to be the 'aim component' of the scenario. The plan is to detect the air conditioning system with the portable reader and change the installation parameters. Afterwards, the result would be observed in the local computer which is located in the next room after the software is refreshed, this will update the BIM model according to the updated database in the cloud.

In other for the objective of the scenario to be realized, the BIM database had to be developed in Microsoft Access. This was undertaken by exporting the Revit Architecture 2012 model to MS Access through Open Database Connectivity (ODBC); this feature is available in Revit. The ODBC exports the BIM and creates database tables for model types and instances. **Error! Reference source not found.**is a snapshot of Microsoft Access 2013, where the exported BIM database is open. At the left side of the figure is the long list of tables created for each element and also, each element type. Each table contains all of the parameters of the element as different fields and values of the fields for different element which is listed in the table. As it is viewable in **Error! Reference source not found.**, the added parameter of "RFID Tag ID" is available in the data table of the "Mechanical Equipment" which represents the air conditioning system that corresponds to the BIM model in Revit.

In the next step, the exported database will be copied to the Cloud storage to become available for every portable and stationary software through internet. The cloud system has software, which is designed to make the containing files available offline in different devices and if any changes takes place, it would automatically upload the newer updated file and replace the older one with it. Hence, the database would be available for each device offline and in case any changes taking place by any of the users, the older database file will be replaced by the newer updated one.

Another functionality that is expected from the software program of the portable reader is the inherent ability to detect the chosen RFID tag. It will highlight its reading record and bring it to the top of the tags that are within its reading range; moreover, its reading record is on the read list of the portable reader. Software program on the laptop computer uses Revit`s Application Programming Interface (API) to import the updated database available on the cloud, back to Revit. This process will update the BIM model with the latest available database on the cloud.

5- Results and Discussion

The settings of the BIM model schematic developed for the first scenario in Revit, was modified to show only the elements of which their "Fixing and Installation" parameter`s value is set to "yes". This will change the visibility of the elements only that have this parameter in their defined parameters. The air conditioning system initial "Fixing and Installation" parameter`s value was set to "No"; and so, this means that the air conditioning system hasn't been installed yet. As shown in **Error! Reference source not found.**, which is an illustration of the rendered outputs from Revit i.e. before and after synchronization, the air conditioning system appears after the user changes the values of its parameter. Also, other defined parameters that has been changed by the user with the tablet reader, were available in the updated model`s parameter viewer.

As regards to the component detection, the application was performing as expected and as the user was moving inside room, the read list order was being changed automatically and then, the closest tag would stay on top of the list. Also, after choosing the air conditioning system`s tag as the aim of detection in the program`s setting, it did change the color of the reading record of the component. Furthermore, after selecting the desired component on the mobile device, all of its properties became available and editable on the device.

The results of this scenario were compelling enough to illustrate the updating and synchronization speed on this framework. The method used in this case study i.e. the exporting, updating and importing back the database, needed reopening of the Revit file every time the database had been updated. Reopening the Revit model every time the user wanted to update the model became very time consuming especially on computers with slower processing power. However, this is not the case in the original framework`s method, since it utilizes a cloud system with high computing power that can process the BIM files and illustrate the final result online.

This case study clearly demonstrated the feasibility of the framework for construction projects. It also proved that component tracking and facility management as well as data retrieval would gain lots of speed and accuracy by executing this framework.

6- Conclusion

The presented framework is an outstanding set of tools that provides clear visibility and monitoring competence for every stakeholder of the construction project and it is flexible enough to spread its assistance all over the entire construction supply chain ideally.

This framework is also a transferable framework, meaning that owners of the framework can easily use its RFID equipment and components in their future projects or even use them in different project simultaneously. This would make owning such framework an asset for construction firms and since there are many software based segments, it would become up to date very easily. Using BIM solely, has tremendous amounts of benefits with respect to the construction project management and post-construction`s operations as well as facility management. This framework would add real-time status synchronization of the BIM and fast data retrieval from BIM during construction; besides, it would also provide detailed project and component information for facility managers and maintenance workers. All of these are being executed while the cloud system makes the whole information available globally and unconditionally throughout internet.

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