TOWARDS A SYSTEMATIC PRODUCTION PROGRESS ASSESSMENT BASED ON AR ON BIM – PREREQUISITES AND FUNCTIONAL REQUIREMENTS

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ABSTRACT: *Many studies on augmented reality (AR) have showed that its usage in Architecture, Engineering and Construction (AEC) sector is beneficial. Nowadays AR technology is growing rapidly, and the AEC sector can only benefit from it. Implementing AR upon Building Information Models (BIM) opens perspectives for new techniques and systems to manage onsite production. Measuring activities progress on a worksite is a time consuming process, and sometimes subject to inaccuracy. This may cause delays and cost overrun. Inaccuracy is mainly due to the lack of a standardized method to measure progress, which is usually done by each stakeholder according to his own customary method. Aiming at expediting and improving the reliability of the onsite production progress measurement, this study presents a conceptual model to measure activities progress and perform schedule updating using AR applied to BIM. For this purpose, the systems structure and design methodology (SSADM) was used to gather all the basic operations from similar systems, identify and eliminate the existing gaps, and add new operations. The concept proposed is based on a 5D (3D + schedule + cost) BIM model, which includes the activities planning, linked to the line items from the bill of quantities (BOQ). By superimposing the 5D model with reality onsite, it is possible to measure the activities progress and the cost up-to-date, through a physical comparison of as-built with as-planned. Deviations from the as-planned (both positive and negative) are detected by the system, which then automatically adjusts the planning according to the real worksite situation. This system reduces measurement errors and keeps the activities plan and costs updated. Measuring all kind of operations using AR onsite is seen as future perspectives.*

KEYWORDS: *Building Information Modelling, Augmented Reality, Progress Measurement, Planning Production*

1. INTRODUCTION

The AEC sector is considered one of the poorest sectors in terms of monitoring systems (Navon & Sacks, 2007), thus it is not surprising that delay and costs overruns are common. AEC's productivity tends to be lower than other industries (Park et al., 2012), and 50 to 85% of the problems that construction faces are associated to delayed or missing information sharing (Howell & Ballard, 1996). One of the areas where information sharing systems can significantly improve the sector's efficiency is production and progress measurement.

Onsite production progress measurement consists of periodically measuring the actual progress and comparing it with the expected progress (Kim et al., 2013). This comparison needs to be extremely accurate; otherwise onsite progress control becomes a challenging and ineffective task. Nowadays measurement systems rely on user perception of progress (Golparvar-Fard et al., 2009), which may cause different values of progress for the same activity. For example, a worker informs the project manager that a wall is 90% executed, but on the next day another worker reports a progress of 70%. This difference may trigger the start of another activity that needed 90% completion of the previous one, when the actual progress could be 70%. To prevent these discrepancies from happen, several studies have been made and proved that using systematic approaches which always rely on the same processes and don't depend on user perception is faster and increases accuracy (Navon, 2007).

Due to the amount of information needed to monitor the progress on worksite, BIM models were brought to the scene as a baseline for project controls and are called "as-planned". Those models carry all design drawings and plans in 3D format, activities schedule and costs, thus becoming 5D models. Thus, several possibilities and critical

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problems of construction progress assessment using BIM and AR have been explored and discussed. However, this discussion has been mostly centered in the combination of AR with other progress assessment technologies, which still result in complex and costly solutions. A concrete conceptual proposal for progress assessment and schedule update based solely on AR would go further in extracting benefits from AR's simplicity and cost effectiveness.

This study proposes a conceptual platform that utilizes augmented reality (AR) as an information tool to retrieve as-built information, compare it to as-planned and, if needed, reschedule activities and for cost control. Thus this study is driven by the research question "How can AR be used to compare as-planned with as-built, measure onsite production progress and make automatic rescheduling?"

The use of AR sets a new way of comparison, mainly because 3D models can be super-imposed upon the work front reality. This then allows visual comparison between both, which can be made by any stakeholder, regardless of his or her perception of as-built. This approach on measuring onsite production reduces the time spent gathering as-built information and the likelihood of errors.

2. SYSTEMATIC PROGRESS MEASUREMENT

Determining as-built status on a worksite is a very labor intense and time-consuming activity (Navon, 2007). In order to reduce time spent gathering all information of the actual status, several researchers have been working on the use of new technologies and concepts to provide AEC sector with a feasible and faster system to measure as-built status and make an automated progress measurement according to as-built information.

2.1 Technology Review

2.1.1 RFID

Navon and Goldsmidt (2002) proposed Automated-Data-Collection (ADC). This method would be based on Radio-Frequency Identification (RFID) tags and used mostly for monitoring interior finishing activities. The building elements would have a RFID tag attached and the worker would have a RFID reader, which would record information from the tags he would pass by. This data would be downloaded once a day, and based on the time each worker spent on a location, activities progress would be calculated.

2.1.2 Time-Lapsed Images

This technique has been used by several researchers because it can replicate as-built based on photographs taken over the construction time. Golparvar-Fard et al. (2009) has developed a concept called D^4AR which uses photographs and videos taken over the time to determine as-built status. This system creates a 3D scenario using advanced programs and algorithms and compares it with the 5D as-planned information.

Zhang et al. (2009) proposed a similar system, which used computer vision to replicate 3D as-built status from 2D images.

2.1.3 Laser Scan

At present date this solution seems the most feasible regarding the accuracy of the collected data. Turkan et al. (2012) used this technology on the construction of the Engineering V Building, University of Waterloo. This technology generates a point cloud with millions of points that creates a 3D scenario of the as-built status. Using 3D object recognition on the point cloud, upon a 3D objects database, these authors achieved an average 96% accuracy match on object recognition.

Using the same technology on a four-floor concrete building in South Korea, Kim et al. (2013) achieved 99% average accuracy on as-built status recognition.

2.1.4 Augmented Reality

Since 2005, AR has been progressively introduced into the AEC sector in number of scenarios. Its main strength is the easiness it offers in representing objects, processes or projects over the real world, thus greatly facilitating user understanding.

Using accurate location devices, such as Global Positioning System (GPS), this technology can impose a 3D project model over a terrain on the exact coordinates. The ability of having a 3D image imposed on real world opens several options for project monitoring, since virtually anything can be imposed, like comments or pictures. The construction site can be designed on a laptop and then be superimposed upon reality in order to detect possible hindrances to beginning construction, thus saving time and money. Comparison made between conventional methods and AR have shown that the latter can greatly increase performance (Lee & Akin, 2011).

2.2 Comparative assessment

The present systems to retrieve as-built information have several limitations depending on the method used.

Using RFID markers is a simple and cheap solution. However the process of gathering as-built information requires all elements to have a marker imbedded, and that marker would have to be read every day.

Time-Lapsed Images method can be considered cost-effective and practical, but have several uncontrollable constrains, such as the weather. Images and videos can be blurry in rainy or foggy weather, and shadows and occlusions from cranes, stairs and formwork can occur. Another concern when using this method is the storage needed to save all the necessary photos and videos (Golparvar-Fard et al., 2009).

Even though the laser-scan methods has proven to be one of the most effective in gathering as-built status, it has several constrains. The equipment should only be handled by people with expertise, it is weather sensitive, which may cause deviations from the desired calibration, it needs an extended objects' database to recognize and match them over the point cloud and the hardware is costly (Markley et al., 2008). This technology requires several scans from different angles to build a complete as-built 3D scenario, thus making it time consuming and subject to human error.

AR is increasingly present in every day's life and it's a matter of time until utilization will become common in construction. Current trends indicate that this technology will be available for any person at any time, and an example of this is Google's new technology "Project Glass" (Google, 2013), which sold as soon as it got to the market. ARCchart, a London-based research firm, forecasts that by 2015 1.6 billion phones on the market will be AR-able. The same study also predicts that the revenue from AR apps will be around 1.7 billion euros for the next two years (ARCchart, 2010)

In the specific field of construction, studies identified a number of areas of application and benefits, such as, visualization aid, architectural assembly guidance and infrastructure tasks (Shin & Dunston, 2008).

2.3 Why AR?

The publication of AR articles has increased in the past few years, especially for construction purposes. Since 1999, 20 articles were published in Automation In Construction (AiC), Journal of Information Technology in Construction (ITCON) and ASCE Journal of Construction Engineering and Management (JCEM) about the use of AR in construction phase (31% of the total articles published about AR in project phases). Also 29 articles, which correspond to 45% from the total analyzed, were about the use of AR for visualization and demonstration phase (Rankouhi & Waugh, 2012).AR's potential for visualization and demonstration can now be considered consensual among researchers.

Wang et al. (2012) proposed a conceptual framework for integrating BIM and AR covering several project stages, including preparation & start-up, transformation of and by resources, monitoring and close down. Also VTT Technical Research Centre of Finland have developed a system which merges AR on BIM called Augmented Reality 4 Building Construction (AR4BC), which was more focused on visualization and merge 3D BIM models on reality (VTT, 2010).

Laser-scan or time-lapsed images are solutions with a high technical component, which require specialized knowledge. These technologies are also costly and complex, when compared with AR solutions. AR's unique feature vis-à-vis previous technologies is the ease of use and visualization. Users can see the construction even before it begins, checking for any constraints or clashes with objects on the work site. AR provides a simple way to enhance user perception of the project, providing visual information imposed on real world helping the user to visually compare elements to gather construction progress. As this technology would be able to use in a portable device, it's ease/precision ratio of gathering as-built would be greatly improved when compared with other available technologies.

2.4 BIM through AR

BIM technology complements AR views ability. BIM models can be viewed by layers or filters, facilitating the progress measure. On the measure process the user could define, for example, "Structure" filter and the 3D BIM model superimpose via AR would only show the elements included on "Structure", instead of showing all elements. For this to happen it's proposed a database presented on chapter 5, with a detailed Work Breakdown Structure (WBS) to divide the BIM model as much as it's needed, so the user can measure all elements without any difficulty. By superimposing differentiated information, selected by the user, through AR, withdrawn from BIM model, the onsite measure process becomes easier and less confusing, reducing the user's visualization to he's needs. Wang et al. (2013) identified numerous opportunities for AR in AEC sector, among them AR portable devices, and stated that this kind of technology is expected to be further utilized in the AEC fields and will enhance productivity, safety and efficiency.

3. METHODOLOGY

In order to gain insight and progress towards the proposal of the new conceptual system envisaged, the Structured Systems Analysis and Design Methodology (SSADM) is used. This method, commonly used in systems development, provides a structured path towards clarifying the system analyzed, with data-flow diagrams and text. SSADM has 7 different stages (Schumacher, 2002):

- Stage 0 – Feasibility Study
- Stage 1 – Investigation of Current Environment
- Stage 2 – Business System Options
- Stage 3 – Definition of Requirements
- Stage 4 – Technical Systems Options
- Stage 5 – Logical Systems
- Stage 6 – Physical Design

Advancing to the next stage is only possible after the previous one is completed, thus reducing the possibility of errors. Although this waterfall methodology may take longer than similar systems approach methodologies, it improves productivity, flexibility, takes into account the user's needs and reduces the cost of re-implementing a new system, due to the ability of structuring processes (Officer, 2012). By analyzing each stage requirements, define connections between processes and limitations, it's proposed a new method to implement AR on BIM models to measure worksite production progress.

4. REQUISITES FOR A PLATFORM BASED ON BIM THROUGH AR

4.1 Business System Options

This stage describes the platform proposed on this study and portrays the solutions found for the shortcomings identified in the previous stage, as part of the new system proposed.

The method proposed begins with 3D BIM modeling of the construction site. The use of BIM allows the project manager to have all the information regarding the construction elements in a single file, which will reduce the time spent analyzing all shop drawings. In addition, a schedule of all activities should be done according to the bill of quantities and its specifications. It is of major importance that schedule and BOQ are linked, as this allows the measurement of activities and overall cost at any time, based on the current schedule. Integrating the 3D BIM model, schedule and BOQ allows the project manager to have much more control over the project.

Once all the connections between the BIM model, the schedule's activities and the BOQ are established, the next step is to choose a suitable technology to retrieve the as-built status. This study proposes the use of AR technology to obtain the as-built status by superimposing a 3D model over the worksite scenario. The Intelligent Global Positioning System (iGPS) is proposed to acquire user and model location accurately. This technology is based on the local replication of satellite triangulation. Thus, it is not conditioned by direct line of sight to orbiting satellites, and can be used indoors with a precision of less than 1mm (Berlo et al., 2009). This technology still has some limitations regarding the quantity of transmitters and receivers needed, which make its portability less straightforward. However, it is foreseeable that in a near future these will be overcome. Using this technology the 3D model can be super-imposed on the exact coordinates and scaled to the user position, in order to achieve a match between all 3D model elements and their equivalents in reality, thus allowing for an

Fig. 1: Setting as built status

accurate visual comparison by the operator. This overlap can be done through a portable device, like an iPad, smartphone or a laptop, and the comparison can be done by physical interaction with the screen. Matching the real elements is particularly important, thus the model would have to be on exact scale. This will allow the user to identify as-built status by clicking on the screen over the actual element progress (Figure 1). As the user sets an as-built status, the model automatically calculates the percentage concluded of the activity associated to that element, checks if it is within schedule and, if necessary, readjusts the schedule to match the as-built. The interaction between as-built and as-planned schedule will prevent the start of upcoming activities that require previous activities completion, and will keep the schedule up-to-date. This will avoid making-do, one of the major reasons for waste in construction. Koskela (Koskela, 2000) identified this cause for waste and described it as starting one activity without having all necessary means and requisites available for its continuous execution and conclusion.

4.2 Definition of Requirements

As mentioned before, it is of major importance that BIM models, BOQ and activities schedule are linked. Figure 2 portrays the overall platform's architecture, displayed as a data-flow diagram. The process starts with 3D BIM modeling of the construction project. Those models are composed by elements that could contain information like suppliers, materials, quantities, costs, etc. By linking each element to his corresponding line in the BOQ, the model is enriched with added information and organization. As all elements are combined with BOQ information, activity schedules can be also attached, thus providing the latter with a start and end date. For the successful establishment of these connections, those elements should have 7 specific parameters associated:

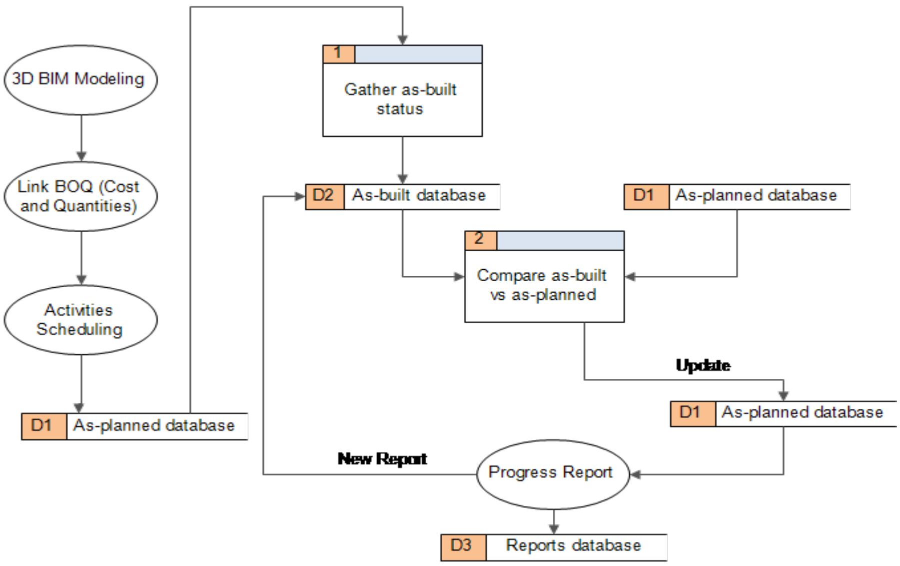

Fig. 2: Platform Architecture

- Material(s)
- Quantity(ies)
- Cost
- Start Date
- Progress
- End Date
- Activity ID

By delivering this information to the "As-planned database", it becomes easier and faster to see any detail related to the project. That database is cathegorized according to the WBS used on BIM model with a level of detail up to the element.

To gather as-built information this platform needs an accurate GPS system and a software to scale the 3D BIM model to the actual user sight, making possible to set an as-built status by visual comparison (Figure 1).

According to this structure, the user can interact to each of the construction elements and set a progress value. As soon as all under construction elements are assigned a value for their progress, the as-built status can be updated into the "As-built database". Its only parameter will be the progress of each element, as this is the only parameter needed to compare with the "As-planned database", shown on Figure 3.

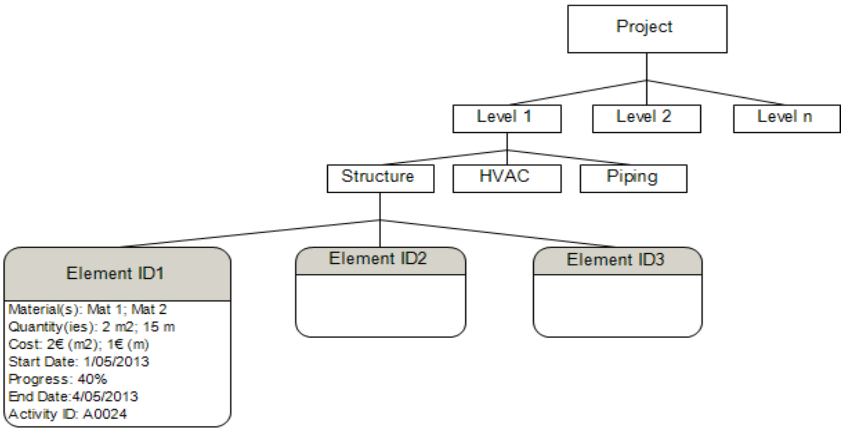

Fig. 3: Database architecture

Each as-built activity progress will be determined based on the average progress of all its elements and their comparison with the as-planned activity progress. For this purpose, each element will be assigned an activity ID. The assumption underlying this comparison is that there is a linear relationship between the time elapsed and the expected percent concluded. For instance, a five days activity should be at 20% completion at the end of the first day. If there is an increase or decrease on its assigned resources, or any other change that affects the duration of the activity in progress, the remaining as-planned schedule will be recalculated and readjusted accordingly. As these changes are made, the respective activity and its subsequent ones should have a new Start and End Date, adjusting the schedule to the new conditions and their implications. This platform is based on a dynamic concept of project controls. Unlike tradicional methods, which rely on static baseline views throughout the project, the proposed system utilizes a dynamic schedule view.

The as-built status will be measured by comparison of the visual input obtained by the portable device on site with the elements of the "as-planned" database. If as-built (BDB) and as-planned (BDP) progresses do not match, the as-planned database will automatically readjust the End Date parameter according to the new expected time remaining to the activity's completion. Thus, the elements' "Progress" and "End Date" will be updated in the as-planned database. The as-planned schedule will be dynamically readjusted in the remaining activities, in order to reflect reality and avoid starting activities which are not yet ready to be started. This provides the user with a realistic forecast of the works onsite, as the activities' schedule always reflects reality on the work front. The corresponding process is shown in Figure 4. This process prevents "making-do", one of the major waste forms found specifically in construction (Koskela, 2004). In order to keep track of the changes that occurred throughout the project, these will be flagged with a visual note added to the respective construction element, indicating a change to the original schedule on it (Figure 5).

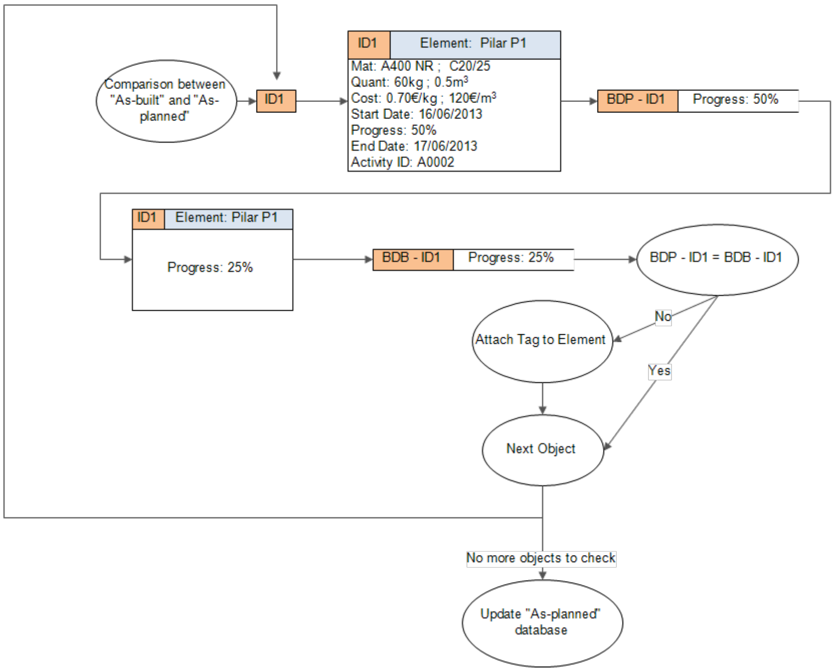

Fig. 4 – Process to compare “as-planned” with “as-built” information

At the end of each as-built information input, a report is produced, which can be customized according to the output envisaged. The elements’ parameterization enables several reports, such as:

- Activities’ Schedule
- Activities’ Cost and Materials used
- Off-Schedule activities
- Overall Progress and Cost

Those reports are then saved in the “Reports database”, which can be accessed any time. The latter will be very similar to the as-planned database WBS. Its first level will be “Date”, in order to enable tracking of project updates, changes and status at any given past time in the project, thus allowing a clear perception of the project’s evolution over time.

Fig. 5: Example of a tag note assigned to a delayed wall with relevant information

4.3 Technical System Options

Using this platform requires a lot of information from the project and a big interaction between 3D BIM model, BOQ and activities' schedule. They are the cornerstones of the proposed platform. Due to the amount of information that is gathered from 3D BIM model, BOQ and activities schedule, this platform will demand a significant involvement in the first stages of the process, as these connections will have to be entered manually. However, once this has been concluded no more big and time consuming inputs will be required. The system will make adjustments and reports based on the quality of the information introduced at this stage, thus it is fundamental that it is carried out meticulously, and all information is introduced correctly.

The system proposed should be mobile and should work effortlessly on smartphones or tablets. This raises the issue of the database storage. In order to avoid importing it to the device, a server client architecture is proposed, where the database is stored at the server and is accessed by the mobile device via wireless network. As-built information gathering will consist of retrieving the AR 3D model from the server and superimposing it to the worksite's images captured by the device's camera, register as-built progress as shown in Figure 1, sending that information via wireless back to the server and finally compare it to the as-planned database.

The user interaction required by this system is very easy, since it is based on visual comparison. This will allow any worker to perform this operation. Specific knowledge is only required to input as-planned information.

5. DISCUSSION OF THE PROPOSED METHOD

The platform presented in this study will expedite project management processes. Project progress is determined faster and more accurately, as it significantly decreases the time spent in gathering as-built status. By creating a database with all reports organized by date, it will be possible to analyze the progress, performance and cost of all activities. This is particularly useful in team meetings, since all information related with onsite works and design is available in a fast and simple way.

The platform proposed aims at low implementation costs. As more and more projects come out in BIM format, it will be increasingly easier to obtain full compatibility. The information required to run the system is part of standard documents in any projects, as it is part of the activities' schedule and of the BOQ. Thus, all the input needed to create "As-planned database" will be available without additional costs. As-built information gathering will be done through equipment of common use, such as laptop computers, smartphones and tablets. This equipment has usually already been acquired by the companies, and its price is significantly lower than other technologic options such as laser scan devices.

Due to its new method of scheduling, this platform provides the user with up-to-date planning anytime throughout the project. In order to always reflect real progress, traditional planning methods must be updated manually and frequently. Otherwise they become obsolete and may trigger wrong decision making. With the dynamic scheduling proposed in this study, stakeholders have a real and accurate perception of the progress, and "making-do" is avoided. Delays or other changes in activities with trigger rescheduling, which will be carried out by changing the as-planned in order to match as-built. As this happens, a tag will be attached to the respective construction element, both visually on the BIM model and on the "Reports Database", in order to keep a record of those changes.

The use of AR seems the way to go in the future and its capacity of providing the user with the exact project model will increase user's perception of the project and decrease the frequency of measurement errors. The proposed platform allows the user to measure onsite progress by marking the actual element's progress on the device, thus avoiding subjective and often inaccurate evaluations of the percent completion of the element.

At its present stage, this platform still has some limitations regarding some types of activities. Earth works are a challenging activity to measure visually. Visual perception may differ from the actual earth moving due to varying depth, and the positioning to measure progress would have to be very specific. Underground or deep interior activities may have problems too, due to the lack of GPS signal. Thus this system is, so far, proposed for structure works, mechanical electrical and plumbing (MEP), heating ventilation and air conditioning (HVAC), tiling and painting.

6. CONCLUSIONS AND PERSPECTIVES

The utilization of AR technology has been proven feasible in AEC sector (Shin & Dunston, 2008). This platform is built upon existing literature by proposing a novel approach to the use of AR for measuring progress, and guarantees schedule relevance and accuracy by utilizing visual comparison between a super-imposed 3D model and the real construction, through AR applied to BIM, for continuously keeping schedules updated. Simultaneously, it keeps track of the schedule changes, through visual flags shown to the user. This addresses the making-do problem, which has been identified as a construction specific type of waste (Koskela, 2004). In addition, this study goes one step further towards developing a progress measurement on the worksite, by proposing a concrete framework that establishes relationships between the construction elements present in the 3D BIM models, the bill of quantities and the activities' schedule.

By importing all BIM elements, provided with 7 parameters to as-planned database, all information regarding construction project is reachable in a few seconds. AR technology was chosen to measure progress because it is fundamentally independent from the user's accurate perception of 2D drawings. Instead a visual approach is proposed by imposing the 3D model over the worksite. As progress of each element is set and recorded on as-built database, then it's compared with as-planned database, checking if any activity is off-schedule. Updating as-built information to as-planned database preserves activities relationships and prevents activities from starting, if any previous one isn't finished. This platform can effectively reduce the amount of measurement errors, as well as increase efficiency by providing visual information to the workers.

The reports database will allow the project manager to monitor every progress detail, such as, costs, activities progress, materials spent, etc., at any given past time of the construction. It's believed that such database will improve management, due to its organization and WBS. As each element has 7 key parameters, it will be possible to measure progress based on different variable and detect flaws or waste patterns by analyzing them.

The authors are now assessing some AR limitations and working on expanding this platform to be suitable to other construction activities, such as earth moving. Positioning is also an important field, which is being looked at. AR can take over significant parts of what is today topography work. It can help the user to determine the exact position of construction elements, with the added value of clarifying what exactly the element will look like, and what will be necessary for its erection. This is a significant step forward from today's topographic marks. Safety activities are also being looked at, in particular choosing the best placement for safety barriers and other collective protection equipment.

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