ABSTRACT

More and more design and construction professionals in Architecture, Engineering, and Construction (AEC) areas have been and now are using Building Information Modeling (BIM). Unfortunately, there were very few efforts exploring the real-time communication and integration of BIM to the site and task conditions, and the interaction of BIM with the field crew. It is envisaged that Augmented Reality (AR) can fulfill this vision effectively through visualizing BIM right into the physical context of each construction activity or task. This paper develops a conceptual framework to investigate how BIM can be extended to the site via AR. Human factors are the core principle to investigate on, considering that AR, by nature, involves the human sensations with both real and virtual information sources. It is also found that AR should be ubiquitous and work together with accurate positioning technologies such as laser pointing.

INTRODUCTION

A wide range of new computer-based tools have been explored to support the Architecture, Engineering, Construction and Facilities Management (AEC/FM) (Froese 2010). More and more design and construction professionals in AEC/FM have been and now are using Building Information Modeling (BIM). Predominant work has been focused on how BIM can enhance the communication and collaboration among the stakeholders (e.g., 3D representation and modelling, engineering simulation, 4D CAD, virtual construction, evaluation and documentation, etc.) along the project life cycle, which is typically constrained in office environments as well as in the form of conventional desktop computers. Information designed in BIM should be eventually applied in the construction site in order to fulfill its maximum potential and promises. For example, 88% of the BIM projects use BIM as a representation tool (McGraw-Hill Construction 2008). Unfortunately, there were very few efforts investigating how to bring BIM effectively into construction site. For example, a very preliminary initial attempt has been done by Woodward et al. (2010) to develop a prototype to AR powered 4D BIM. Only 18% of the BIM projects use BIM as a construction monitoring tool (McGraw-Hill Construction 2008). Examples of hurdles of bringing BIM into the onsite include the problem with large quantity of data, and the context awareness of where to access what BIM data. Therefore their full potential cannot be realized without being widely applied in construction site which is a critical phase along the project’s life cycle. The focus of this paper is to discuss the scientific and
practical rationales of extending BIM onto construction site for daily detailed activity level of work and how AR can play a critical role in facilitating the effectiveness of BIM information access.

It is envisaged that Augmented Reality (AR) (Milgram Colquhoun 1999; Milgram and Kishino 1994) can fulfil this vision effectively through visualizing BIM data right into the physical context of each construction activity or task. Essentially the conventional role of AR is the visualization end. Any data fed into this end has to be pre-processed in a manner to make the data make sense to the end users. This paper develops a theoretical framework to investigate how BIM can be extended to the site via AR. In another word, AR can be the extended version of the BIM on site.

This paper presents the “BIM + AR” as a pioneering and innovative concept of construction ICT. BIM provides relatively static and pre-defined data and information. AR provides onsite augmentation as well as onsite sensing considering vision-based AR can be a tracking tool as well. AR, as a class of easy-access interface, has the potential to change how site manager, construction workers, etc. interact and access to digital technical information in BIM.

FRAMEWORK OF BIM+AR

Designing in BIM is one thing, and effectively building according to as planned is another thing. During construction, BIM information should drive the physical deliverables of the construction work. The discussion of the practical rationale and case illustrations for BIM+AR use in construction site focus on a few key areas relevant to construction activities.

Construction consists of input components such as materials, labour, time etc., output components such as quality, waster, cost and schedule overruns, and the construction process which includes start-up and preparation, transformation of and by resources, monitoring, and close down/clean up (Bernold and Abourisk 2011). In many cases, although the components are not complicated on their own, the total number of components in one project is magnificent, and the causal connections between these components are complicated (Froese 2010). Froese (2010) classified these connections into four views: product, process, resources, and time. Table 1 gives the vision of how BIM+AR can play a role in each of the views concerned. AR is more like an “information aggregator”, which can collect and consolidate the information from the individual tools such as BIM, context-aware sensors, etc. AR could allow users to define and work with the inter-relationships between these views, find relevant information by following the relationships from one tool to another, and analyse inter-related information through various visualization techniques.
Table 1. The Role of BIM+AR in Product, Process and Resources View

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<tr>
<th>View</th>
<th>Descriptions</th>
<th>Role of BIM+AR</th>
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<tbody>
<tr>
<td>Product</td>
<td>Refers to an explicit representation of the deliverable—the information deliverables that describe the constructed facility as planned in the project plans. The collective sum of all of this information can be thought of BIM. Time dimension of product refers to the pre-defined milestones of the planned project progress.</td>
<td>AR emphasizes a continuum that flows from the virtual facility to the physical one.</td>
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<tr>
<td>Process</td>
<td>Refers to the construction and production method to convert resources to physical product. The time dimension of process refer to the sequential ordering of tasks, which can be realized in 4D CAD in BIM.</td>
<td>4D CAD can be visualized by AR via time-based animation.</td>
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<tr>
<td>Resources</td>
<td>Physical resources (e.g., materials, tools, equipment, labour, etc.) required to be matched with constructing any physical component. Time dimension of resources refer to the temporal delivery status tracking from procurement to final installation.</td>
<td>In order to identify, track and monitor each individual physical onsite resource, AR can link them to BIM and ERP with sensing/tracking technologies such as Barcode and RFID.</td>
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Arayici (2011) created the “generation–communication–evaluation–decision-making” cycle which refers to the typical routine of onsite decision-making. AR can create an onsite visualization-based interactive and cooperative decision-making platform for site personnel to develop effective alternatives or solutions. For example, architects designing the building envelope closely interact with engineers developing the steel structures of the building. When architects and engineers discuss complex geometrical relationship for example facades with the “generation–communication–evaluation–decision-making” cycle. The conventional way is to create and use a physical mock-up which is time-consuming and inaccurate, considering that many features and properties are lost. Sometimes, computer-generated sketches can be made as an alternative before the meeting, but they are still insufficient for evaluation and collaboration. With BIM+AR, the 3D BIM models with detailed features and properties can be visualized directly onsite right before site personnel to support dynamic generation of site and work solutions. It is envisaged that BIM+AR can make the “generation–communication–evaluation–decision-making” cycle work more effectively and productively.

Based on the “views” explained in Table 1 and the “generation–communication–evaluation–decision-making” cycle, Figure 1 depicts the framework of BIM+AR for site use. Table 2 reinforces and enriches the framework with BIM+AR examples in a matrix formed between vertical dimension “generation–communication–evaluation–decision-making” cycle and the horizontal dimension of 4-stage construction process. The framework starts from breaking a project down into smaller construction site activities. One of the fundamental mechanisms that the construction industry has developed for dealing with complexity is the approach of Work Breakdown Structure (WBS) which decomposes project work into well-defined work tasks and then assign each work task to a specialist group. Each group works with the subset of project information that is relevant to their work represented in a form suitable to their particular task,
thereby creating a specific view of the project. To be sure, each participant has some notion that their work must follow certain work and must precede other work, and that certain actions or outcomes of their work will influence others (Froese 2010). Also, a few individuals in the project have explicit responsibility for overall coordination (e.g., the project manager). WBS can be the structure to organize digital contents in AR. A dynamic AR is therefore analogy to the site map in a Web, so that the field crews and managers can have a higher awareness of where they are browsing in AR. The WBS standard template can comprise of five layers: section layer, position layer (e.g., top structure), numbered layer (e.g. #10 girder), component layer (e.g. rebar cage of #10 girder), and function layer (e.g., schedule monitoring, or construction method). This allows AR to understand and match the specific entity in BIM model with the actual entity in the real world.

Examples of tracking components for context aware layer as depicted in Figure 1, are 2D barcode, 3D barcode, and Radio Frequency Identification Technology (RFID). These trackers are mobile and ideal for field AR+BIM applications. Typically tags are used to record progress created within an infinite number of properties, e.g. date, number, text lists. A separate tag will be used for each workspace or location to record activities/handovers. Tags are created with a certain number of pre-defined or scheduled separate activities that need to take place in order for a specific component (e.g. a concrete slab) to be constructed. The site operative can enter the date of completion and record comments of each activity. There can be a direct link between the BIM model to the AR database, both of which contain drawings and documents linked to a specific component. Database can include construction zoned plans and details and general arrangements and building services working drawings.
The proposed work pattern based on BIM + AR as in Figure 1 is as follows: in this way, the overall concerns of the site work are more prominent to all concerned parties and are easier to identify and explore the alternative solutions.

1. Designing and planning construction tasks starts with the creation of prototypes or models in BIM, which contain geometric information and non-geometric design and management information, such as material properties, supplier information, cost and schedule data, organizational information, etc.
2. BIM model is then used to organize the production process.
3. Every worker views their role as carrying out their tasks by drawing information from the same BIM model via AR, and using the virtual AR models to explore the interaction of their work with others and to support effective communications.
4. Place their results back into the BIM model through AR annotation or commenting.

Table 2 discusses the practical rationale and case illustrations for BIM+AR relevant to construction site activities.
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<th>Table 2. BIM+AR Examples in a Matrix Formed between “generation-communication-evaluation-decision-making” Cycle and Construction Process</th>
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<tr>
<td><strong>Start-up &amp; Preparation</strong></td>
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| **Generation** | • Onsite work planning: plan and coordinate the site activities and ensure future access.  
• Safety instruction and management: prior to the task of a worker, AR can visualize peripheral digital safety instructions (e.g., a check list of operating at heights, machinery operation safety).  
• Inventory and materials checking: know what type of material or building element is delivered and procured, in what quantity, where they are stored, when to be delivered | • Spatial planning: understand the spatial relationship between the physical construction materials, reachability of labour, spatial constraints and the equipment physical effectors.  
• Spatial judgement: gives a more straightforward view to give site manager a sense of how building element fits to the space on constructions site. | • Communication of 4D animation onsite among site personnel to gain a better sense of the as planned progress. | Quality inspection and control through comparison between the physical as built component with the AR visualization of as planned component |
| **Communication** | • Communication with clients: have the final renovation design layout in the context of real environment can give clients a better spatial sense of how the design fits to the existing facility and change accordingly to satisfy clients.  
• Onsite communication and coordination (Resulting plan): onsite discussion and coordination between different parties on site before the immediate construction, e.g., exchange of information between onsite architects and engineers. | • Some plans may be more effectively comprehended to reduce misinterpretation by registering virtual models with objects in the real scene. It may be easier to build quickly and precisely as planned, especially complex designs in constrained spaces.  
• Complex geometry: communicate complexity and relations between disciplines both internally and externally.  
• AR can be the site-version of BIM for integration and coordination to carry out the real time of clash detection function onsite between for instance the to be installed virtual components with existing components in place.  
• Guide construction workers through the construction of actual buildings and help to improve the quality of their work.  
• Coordinate between different working methods, different goals and level of ambition, among different specialties.  
• Swift identification of sequence errors and clashes, flexible reflection of design and work sequences changes, etc. | • Compare as built data with as planned data (BIM) via AR to monitor and control the project progress.  
• Communication of 4D animation onsite among site personnel  
• Procurement between the production and construction site | The use of AR models facilitated a concurrent approach to allow contractors and suppliers to work with several crews at the same time and helped reduce the lead time.  
• Improved data integrity, intelligent documentation, distributed access and retrieval of building data |
| **Evaluation** | • Discovering design errors and potential spatial and schedule conflict analysis before construction, assembly, and installation.  
• Visualizations to allow checking against design intent | • Better visual control of complex geometry and complex relationships  
• Less failure and clashes  
• Enhanced performance analysis | Better visual control of complex geometry and complex relationships  
• Less failure and clashes  
• Enhanced performance analysis | have the final product visualized in the context of real environment can give workers a better understanding of the surrounding workspace around so that an appropriate method can be planned to suit.  
• Better and quicker quality control and assurance  
• Daily report |
| **Decision-Making** | • Make well informed decisions on resource allocation and dynamic adjustment  
• Make decision earlier in the process. Better quality of the decision informed made.  
• Better for engineering decision making because of the availability of onsite measurements.  
• Better planning can reduce the waste of overproduction, the waste of waiting, the waste of unnecessary movement, and the waste of unnecessary inventory. | • Can help to set and adjust task priority  
• Can reduce the waste of waiting, and the waste of inappropriate processing  
• Facilitate simultaneous work by multiple disciplines: for example, if mechanical piping has been installed half way, the HVAC want to start the work, then visualize HVAC virtual design onto the real mechanical piping will let people to decide if space allows the spontaneous work to happen or not.  
• Adjust schedule based on the current progress  
• Can reduce the waste of defects | • Adjust schedule based on the current progress  
• Can reduce the waste of defects | Better and quicker quality control and assurance  
• Daily report |
SUMMARY

There are more and more design and construction professionals in architecture, engineering, and construction (AEC) areas who have been and now are using Building Information Modeling. Predominant work has been focused on how BIM can enhance the communication and collaboration among the stakeholders (e.g., 3D modelling, 4D CAD analysis, evaluation and documentation, etc.) along the project life cycle, which is limited in an indoor environment or constrained into the form of the conventional computers. Information designed in BIM should be eventually applied in the construction field for guidance. Unfortunately, there are very few efforts looking into the real-time communication of BIM data to the construction site and the interaction of BIM data with the field crew. Therefore, a class of easy-access interface of interacting with digital BIM data is very essential to site manager, construction workers or others. Augmented Reality (AR), which can insert digital information into the real workspace, has the potential to change how people interact and access to technical information.

Essentially the conventional role of AR is the visualization end. Any data fed into this end has to be pre-processed in a manner to make the data make sense to the end users. This paper develops a theoretical framework to investigate how BIM can be extended to the site via the “hand” of AR. In another word, AR can be the extended version of the BIM on site. Human factors will be the core principle to investigate on, considering that AR, by nature, involves the human sensations with both real and virtual information sources.

REFERENCE: