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Integrating Augmented Reality with Building Information Modeling: Onsite construction process controlling for liquefied natural gas industry

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ABSTRACT

The extent of effectiveness of real-time communication within BIM environment is somehow restrained due to the limited sense of immersion into virtual environments. The objective of this paper highlights the need for a structured methodology of fully integrating Augmented Reality (AR) technology in BIM. Based on the generic review of BIM in construction, this paper forms the rationales for the onsite information system for construction site activities, and then formulates the methods of configuring BIM + AR prototypes. It is demonstrated that, extended to the site via the "hand" of AR, the BIM solution can address more real problems, such as low productivity in retrieving information, tendency of committing error in assembly, and low efficiency of communication and problem solving.

1. Introduction

Nowadays, Building Information Modeling (BIM) facilitates the convenient and highly-efficient multi-professional collaboration. By synchronizing the central files, various professionals are able to share the same data set and operate on a unified platform. It is noted that the technical kernel of BIM is comprised of 3D visualization and the corresponding building information management mechanisms. First of all, with 3D visualization, it is easier to demonstrate design intent of cross-disciplinal professional engineers [1], and enable intuitive understanding, facilitate timely communication and error checking in drawings. Secondly, since large construction projects are featured as large in size, high in interspace and densely-populated, it is easy to cause significant impact to the safety of personnel and loss to property once an emergent situation occurs. Mapping the 3D models of BIM with the intelligent systems can simulate unexpected situations by computer and contingency plans can be made in advance. In addition, utilizing the 3D visualization technology of BIM, the construction unit can publish project construction information and operational information through the internet and other means of mass media. This provides it with a chance of improving the public participation, economic, environmental and the social benefits, as well as other comprehensive benefits.

During the past decade, BIM concepts have been actively explored for expanding the usage into an nD environment [2]. It is encouraging that this expansion is moving away from merely 3D modeling, towards more engineering analyses and various construction business functions [3]. For example, engineering analyses in such areas as structure [4], energy [5], disaster prevention in the design phase [6], construction planning [7], scheduling [8], project control [9], safety in the construction phase [10], and even interactive systems in the maintenance phase [11].

Defined as the combination of real and virtual scenes, Augmented Reality (AR) has been explored for a number of applications in the AEC area [12], e.g., maintenance [13], manufacturing [14], training [15], medicine [16], 3D video conferencing [17], computer assisted instruction [18], entertainment [19], construction design [20] and so on. With AR, a person is able to combine the 3D object into the normal viewing perspective without losing any of the advantages of object movement and individual movement in real-world environments. AR is envisaged to become the media to convey BIM effectively into the construction site, as an invisible and extended hand of BIM. Recent advances in computer interface design and hardware power have fostered a certain number of noted recent AR research prototypes or test platforms in the arena of construction [21–30]. More research, particularly regarding user issues, should support this technology development trend. More practical application domains of AR technology can be found in a thorough survey by Wang [31].

Wang et al. [32] identified the following practical rationales for the onsite information system for construction site activities (See Table 1). It is envisaged that BIM + AR can fulfill these visions effectively through visualizing BIM data right into the physical context of each construction activity or task. Essentially the conventional role of AR is the

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visualization end. Any data fed into this end has to be pre-processed so that it makes sense to the end users.

There are very few investigations or research work on how BIM can be used to support field work such as onsite planning and coordination, and collaborative information sharing. Rarely has work been done or even conceived of to use BIM on construction sites to guide the hands-on physical tasks of workers. This implies that computer-generated dimensions, textures, spatial location and environments provide a limited level of 'realism' due to a lack of sensory feedback and are therefore unable to afford perceptual and cognitive benefits [34]; the digital building information in BIM is subject to a lack of interaction between the virtual and real worlds, which to some extent, hinders the overall grasp of digital project information. This limits the real-time communication and integration of BIM to the site and task conditions, and the interaction of the field crew with BIM.

However, as a class of easy-access interfaces, AR has the potential to change how the site manager, construction workers, etc. interact and access digital technical information in BIM. Essentially the conventional role of AR is the visualization end. Any data fed into this end has be pre-processed in such a manner to make the data make sense to the end users. A framework of the integration of BIM and AR for onsite information sharing and communication has been done by Love et al. [35]. However, there is still a lack of sufficient investigations or insights on how BIM can be integrated with AR. The current research work has not answered the questions on how to effectively visualize BIM right into the physical context of each construction activity or task, how BIM together with AR-based visualization can effectively manage or interact with the information database provided on site, and how BIM together with AR can facilitate the actual onsite assembly.

In this paper, AR is investigated to develop solutions for a (Liquefied Natural Gas) LNG mega project to facilitate the efficiency of onsite project progress monitoring and control. AR can be used to visualize a facility in the context of the real workspace to enable the 'as built' progress against 'as planned', since the as planned facility is right in the context of the real workspace to enable project managers, workers and other stakeholders to review the building progress. An AR system can enable the site management crew to be aware of the actual progress of a project as compared to as planned, which forms a solid basis for justifying progressive payment. This study specified and prototyped a suite of BIM + AR systems, partially demonstrating the proof-of-concept of using BIM + AR for project control, procurement monitoring, visualization of design during construction and linking paper to physical. From the perspective of mental tasks involved at these levels [36], it is believed that the primitive and composite mental tasks could be readily applied within a BIM + AR environment. When assessing the feasibility of using BIM + AR for the field work process, three major mental aspects need to be addressed how information is obtained, attention distraction from disturbance and processing from memory (visual representation, short-term and long-term memory). This classification has been utilized for structuring our theoretical foundation, in order to analyze and reveal the underlying issues associated with human information processing that could be addressed by appropriate BIM + AR based technologies. A considerable amount of time and effort may be undertaken to determine the location as well as reading procedural and related information. According to Hou and Wang [24], AR can be used to expedite tasks more efficiently and effectively, as information can be made readily available in real-time and real context. Enabling salient information to be available on demand, particularly during operation and maintenance phases, can improve decision-making. The use of AR should lower the frequency of switching between information resource (paper drawings or computer) and work piece tasks by integrating the required information into activities and therefore reduce the time and energy associated with repetitive switching [37]. For many tasks, accurate performance requires not only that pertinent information be retained temporarily, but also that the information be acted on quickly [38]. In the case of AR, information is directly inserted into a person's real world view of the task, releasing part of the short memory occupied by those items and therefore facilitating efficient retrieval of information from memory. Technically, AR can insert digital information into the physical context of the workspace in a real time manner. In this paper, mobile devices such an iPad, iPhone and PC tablet are used as the platform to enable AR. A Head-mounted Display (HMD) is also used to explore alternative display modes and their applicability in heavy-hand-occupied activities and tasks. It is envisaged that such mobile-device based AR can be applied to a number of activities such as inspection systems, supporting touch-based computer data acquisition for recording construction surveys and collaborative and information-sharing platforms.

2. BIM + AR systems

In the following sub-sections, the employment of an integration system of BIM and AR is illustrated, to which the above seven rationales can be mapped (Table 2). Each of the following sub-sections will be demonstrated to understand the proposed BIM + AR applications in construction Projects. For technical details of each prototype, the readers are referred to the report [40].

2.1. System 1: BIM + AR Walk-through

The practice of having an index sheet with a mass of drawings in the site offices that is 'thumbed through' to look at a specific detail is time-consuming and tedious. Using AR, the users can effectively assess the information from BIM + AR Walk-through. AR can enable walk-through functionality that can facilitate design and constructability review process right on the site, considering that AR, by nature, involves the human sensations with both real and virtual information sources. Traditionally, design is realized through the production of 2D shop drawings from a 3D object model. The traditional method of having an index sheet and with a mass of drawings in the site offices that are 'thumbed through' to look at a specific detail is time-consuming and tedious process. The generation of 2D drawings from the 3D object models is challenging, even negatively impacting on the time schedules and on the resources needed and the process of generating (or extracting) 2D drawings is perceived as time-consuming and as one of the greatest challenges in the project [40]. Additionally, another perceived challenge is the limited possibility to rapidly make 3D drawings for spontaneous needs and meetings. Therefore, a long-term approach to tackling these challenges could be to strive for a situation where the 3D object models replace the need for 2D [41]. This AR Walk-through functionality can facilitate design and constructability review process. Specifically, this AR functionality can provide a full 3D interactive solid model of the design, giving the workers a visual understanding of details. The functionality is given in Table 3.

The 3D model of an LNG plant is massive and it has to be more user-friendly if the AR and VR technologies are to be adopted and widely used in LNG. A layering concept and prototype are developed, which basically pre-split up the entire LNG 3D model into layers, for example, the first level, the front layer. Therefore, the entire LNG 3D model might end up with different layers. As depicted in Fig. 3, the workers can review the structure of the LNG module by pre-defined levels, layers and specialties such as piping, electrical and mechanical. To facilitate the on-site design review process, this AR scenario enables the on-site workers to scrutinize the design by 'walking into' the difference levels from what is seen in Fig. 2 to what is seen in Fig. 4. The workers can zoom in and out for details and look around as well. Therefore a high level of constructability is achieved and conveyed clearly to the site via AR. The 3D reinforcement detailing reduces the periods of time usually required for alteration to drawings, saving time for all parties involved. By trusting this, the model checking time is significantly reduced. A full 3D solid model of concrete frame filled with rebar was produced with AR. This amounted to detailing reinforcement using 3D