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APPLYING AUGMENTED REALITY FOR DATA INTERACTION AND COLLABORATION IN BIM

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Abstract. Building Information Modelling (BIM) is expected to enable efficient collaboration, improved data integrity, distributed and flexible data sharing, intelligent documentation, and high-quality outcome, through enhanced performance analysis, and expedited multi-disciplinary planning and coordination. Despite these apparent benefits, the collaboration across the architecture, engineering and construction (AEC) disciplines is largely based on the exchange of 2D drawings. This paper reports the findings from a research project that aims at developing measures to enhance BIM-based collaboration in the AEC industry. Based on focus group interviews with industry participants and case studies of BIM applications, visualisation was identified as an interactive platform across the design and non-design disciplines. It is argued that visualisation can enhance the motivation for BIM-based collaboration through integration of advanced visualisation techniques such as virtual reality (VR) and augmented reality (AR). An AR interface for a BIM server is also presented and discussed in the paper. AR can open up potential opportunities for exploring alternatives to data representation, organisation and interaction, supporting seamless collaboration in BIM.

Keywords. BIM; augmented reality; design collaboration.

1. Introduction

As the buzzword in the architecture, engineering and construction (AEC) disciplines, building information modelling (BIM) is an IT-enabled approach that involves applying and maintaining an integral digital representation of all building information for different phases of the project lifecycle in the form of a data repository. BIM is expected to enable efficient team collaboration, improved data integrity, distributed and flexible data sharing, intelligent documentation, and high-quality project outcome, through enhanced performance analysis, and multi-disciplinary planning and coordination (Fischer and Kunz, 2004; Haymaker et al., 2005; Ellis, 2006).

While the potential benefits of BIM in terms of information sharing and project collaboration may seem evident, the adoption rate of BIM has been rather slow (Johnson and Laeppel, 2003; Bernstein and Pittman, 2004). The literature attributes such slow uptakes to both technological and cultural reasons. In a series of large-scale focused group interviews conducted across the AEC disciplines by the authors, data interaction and collaboration issues have been identified as one of the important aspects for future BIM development, echoing some early studies. Like general computer-aided design (CAD) / computer-aided manufacturing (CAM) applications, to a certain extent, current BIM technologies (ranging from domain-specific BIM applications to fully inter-disciplinary BIM technologies such as BIM model servers) lack intuitive modes of data representation and interaction for supporting effective multi-disciplinary collaboration. Such issues have become most critical as BIM utilises much larger data sets with more complex data types shared by a wider range of users, compared to general CAD / CAM systems that often serve a single discipline only (Gu et al., 2009).

This paper discusses an integration framework adopting augmented reality (AR) as the primary interface for a BIM server. This represents a novel approach for data interaction and collaboration in BIM. AR enables a design environment where the digital information generated by a computer is inserted into the user's view of a real-world scene (Milgram and Colquhoun, 1999). AR has been perceived to effectively support collaboration works in the architectural practice (Wang et al., 2008). This can open up potential opportunities for exploring alternative approaches to data representation, organisation and interaction for supporting seamless collaboration in BIM. The paper firstly discusses the technical requirements for a BIM server as a collaboration platform based on: (1) a case study conducted with a state-of-art BIM server to identify its technical capabilities and limitations; and (2) an analysis of features of current collaboration platforms used in the AEC industry. The findings are classified to include (1) BIM model management related requirements; (2) design review related requirements; and (3) data security related requirements. An integration framework is then proposed, supporting the above technical requirements for design collaboration in the AEC disciplines. The novel use of AR for data interaction and collaboration in BIM can inspire new business cases that foster future innovations.

2. Background

2.1. BIM ADOPTION

Based on relevant works (Johnson and Laepple, 2003; Bernstein and Pittman, 2004; Holzer, 2007; Khemlani, 2007; Howard and Bjork, 2008), and focus group interviews with key industry players, we have identified the main factors that affect BIM adoption (Gu et al., 2008; 2009). The perception and expectation of BIM against the industry's current practice are summarised in terms of the following three main aspects: tools, processes and people.

Tools. The expectations of BIM vary across disciplines. For design disciplines, BIM is mainly an extension to CAD, while for non-design disciplines such as contractors and project managers, BIM is more like a intelligent data management system (DMS) that can quickly take-off data from CAD packages directly. While there are evident overlaps, BIM application vendors seem to be aiming to integrate the two requirements. The existing BIM applications are not yet mature for either purpose. Users with CAD backgrounds, such as designers, expect BIM servers to support integrated visualisation and navigation that is comparable to their native applications. Users with DMS backgrounds, such as contractors and project managers, expect visualisation and navigation to be important features of BIM servers that are missing in current DMS solutions. Hence, these findings suggest that visualisation has become an interactive platform across the design and non-design disciplines (figure 1). Therefore, it is likely that more realistic, accurate and intuitive visualisation capabilities can enhance the motivation for BIM-based collaboration across the different disciplines.

Processes. BIM adoption would require a change in the existing work practice. An integrated model development needs greater collaboration and communication across disciplines. A different approach to model development is necessary in a collaborative setting where multiple parties contribute to a centralised model. Standard processes and agreed protocols are required to assign responsibilities and conduct design reviews and validation. Experience from DMS will be useful for data organisation and management, but organisations will need to develop their own data management practices to suit their team structure and project requirements. Different business models will be required to suit varied industry needs. A BIM model can be maintained in-house or outsourced to service providers. In the latter case, additional legal

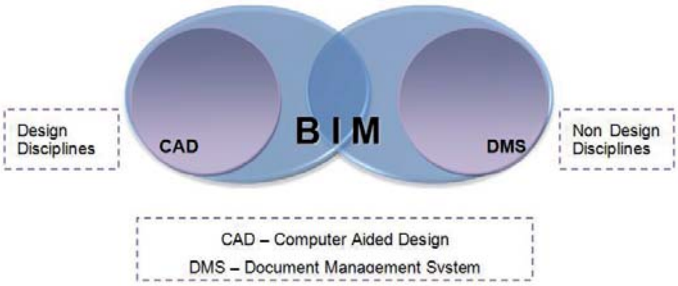

Figure 1. Visualisation as an interactive platform across design and non-design disciplines.

measures and agreements will be required to ensure data security and user confidence.

People. New roles and relationships within the project teams are emerging. Dedicated roles, such as BIM model manager and BIM server manager will be inevitable for large-scale projects. Team members need appropriate training and information in order to be able to contribute and participate in the changing work environment.

In summary, as BIM matures, it is likely to integrate the existing CAD packages and DMS into a single product. For BIM to succeed and be adopted widely in the industry all stakeholders have to be informed about the potential benefits to their disciplines. Earlier works show that (1) the lack of awareness, (2) the over-focus on BIM as advancement of CAD packages only, and (3) the relative downplaying of BIM's document management capabilities have inhibited the interest of non-design disciplines of the AEC industry. A user-centric BIM research has to be more inclusive, since the success of BIM adoption lies in the collective participation and contribution from all stakeholders in a building project. For our research, the above understanding of BIM adoption highlights that building data representation and interaction is one of the most important aspects of BIM. Like general CAD applications, current BIM servers lack intuitive and flexible interfaces for supporting customised needs from different disciplinary users and the effective collaboration among them. This has become most critical as BIM servers utilise much larger and more complex data sets to be shared by a wider range of users across all AEC disciplines, compared to a general CAD application that often serves a single discipline only.

2.2. AUGMENTED REALITY IN DESIGN COLLABORATION

In building projects, the difficulties in information sharing between different disciplines often result in delays in decision-making as well as errors in project outcomes. This section introduces current AR applications that aim to improve interdisciplinary design collaboration. Several attempts have been made to address this issue by implementing knowledge integration and sharing between disciplines in AR-based environments. These applications can allow multiple disciplines to contribute and interact with the digital building information in a seamless and intuitive manner during design collaboration. For instance, Wang and Dunston (2008) develop an intuitive mixed reality environment called Mixed Reality-Based Collaborative Virtual Environment (MRCVE) to support the collaboration and design spatial comprehension in collaborative design review sessions for mechanical contracting. The environment can be a face-to-face setting or distributed over network. Wang and Chen (2009) conduct a study investigating how AR can facilitate the collaborative work of multi-disciplinary stakeholders in the context of urban design. The FingARtips project (Buchmann et al., 2004) also applies AR, in which the users can wear head-mounted displays or virtual glasses to view digital information that is overlaid onto physical objects in the real world. However, this application is limited by the number of concurrent users the system could technically support at a given time. The high cost of equipment for individual users also makes the application infeasible to be used by large inter-disciplinary design teams. Furthermore, the tracking of the system is inaccurate, i.e., it is very difficult to have the system thoroughly evaluated for accuracy and precision. Another example of such is a MetaDESK called Tangible Geospace (Ishii and Ullmer, 2006) which is essentially a Tangible User Interface (TUI) system. It has been applied in the field of urban planning. This application aims to support synchronous design collaborations in a face-to-face manner. In this system, several physical objects are used to support designers' tangible interactions with the site. These objects are placed on a translucent holding tray on the metaDESK's surface. During the collaboration process, by placing a miniature model (phicon), such as the Great Dome of the MIT campus onto the MetaDESK, a 2D digital map will appears underneath the MetaDESK bound to the Great Dome miniature at its actual location on the map. Simultaneously, the arm-mounted active lens will display a 3D view of the MIT campus with the Great Dome and its surroundings in perspective. The main function here is for exploring existing designs, the prospects for supporting interdisciplinary collaboration has not been examined.

3. A BIM server as a collaboration platform

A review of 2D collaboration platforms currently used for inter-disciplinary collaboration in the AEC industry and a case study with an existing BIM server have been conducted to identify the technical requirements of a BIM server as a collaboration platform. Identification of these technical features is important for the assessment of potential integration of AR with BIM.

This section summarises the expected technical requirements and features of a BIM server, and provides the basis for the framework discussed in Section 4. Singh and Gu (2009) categorise the primary technical requirements of a BIM-based collaboration platform as below.

3.1. BIM MODEL MANAGEMENT RELATED REQUIREMENTS

These features and technical requirements are directly related to the storage, operation and maintenance of the BIM model that contains 3D geometries, 2D documents, and other related building information.

3.1.1. Requirements for model management and organisation

- **Model repository.** A BIM server data repository that can be linked to other federated data repositories to increase data capacity and efficiency of the server.
- **Hierarchical model structure.** A BIM model on a server is organised in a hierarchical structure, which should be flexible.
- **Sub-models, and objects with different levels of details.** The BIM server should provide the ability to *map objects with different levels of details*. Users should be able to navigate and switch across different views through simple functions (toolbars) and shortcut keys.
- **Object and model history,** such as ownership and modification records, should be maintained in the data repository.
- **Object property.** It should be possible to *overlay additional object properties* and data. For example, images from as-built structures can be linked with corresponding objects in the original model, and object properties can store related data such as the quality of construction.
- **Public and private model spaces.** Public model is accessible to all users with access rights. Private model could be model in progress, but not ready to be shared with others.
- **GUID.** Globally Unique Identifier (GUID) allows each object to be uniquely identified, preventing duplication.

3.1.2. Requirements for model access and usability features

- **Hierarchical model administration structure.** BIM server administration deals with management and allocation of model access rights, data control and security. BIM sever should allow administrative structures that reflect and support existing organisational practices.
- **Download / upload model.** Different modes of interaction for model download (upload) are possible to include shortcut keys and drag and drop options.
- **Check-in / check-out and version lock.** *Check-in* options should allow addition of new partial model or merging with existing model. Similarly, *check-*

out options should allow download of the complete model or partial models using different modes of interaction. A *check-out with lock* feature should be provided to notify other users that the checked-out data has been locked and deemed not usable. A *version lock* feature should be provided to lock version of the model after sign-off, as a form of archiving.
- **Model viewing options.** Users should be able to *capture and save screen shots, which is a standard functionality provided across CAD packages*.
- **Documentation and reports.** When downloading a part model there should be options to *generate reports* on parametric, linked, and external information for selected objects and other objects in the rest of the model.
- Users should be able to *generate and export PDF* or other document formats.
- **Integration of information from product libraries.** It should be possible to *create a comparison report for alternative product options*.
- Features should be provided to *validate rules* while uploading the files on the BIM server. Users should have the option to switch validation check on and off.

3.1.3. Requirements for user interface (UI)

Other than the standard UI features, the BIM server interface should include: (1) a model tree view position and 3D viewer position; (2) supports for online real-time viewing, printing and mark-ups; (3) the ability to click on an object, and check what sub-sets it belongs to, and (4) the ability to click on an object, and switch from the sub-sets it belongs to for another sub-set. Users should also be able to customise and choose the UI functions.

3.2. DESIGN REVIEW RELATED REQUIREMENTS

These technical requirements and features are specifically related to design review activities, including various functions needed for design visualisation and navigation, as well as team communication and interaction.

Team communication and interaction. Distributed design reviews may require parallel video conferencing, virtual environments, integration of real-time visual feedback from sites and similar interactive media. BIM servers should also provide the ability to capture and store real-time data from online meetings and reviews.

Design visualisation and navigation. Building projects often result in large data files, which reduce the online navigation and viewing efficiencies. Hence, for effective design review across distributed teams, capabilities to create lightweight 3D data are essential. 3D Model viewers supported or provided by BIM servers should have high data compression capabilities while maintaining the visual quality. It will be useful to provide technical features that allow instant, online mark-ups and tags on a shared document or model being by multiple users during the review.

3.3. DATA SECURITY RELATED REQUIREMENTS

These features and technical requirements are related to network security and the prevention of unauthorised access into the system. In summary, security of data on a BIM server should account for confidentiality, integrity and availability of data.

In addition to these three main requirement categories, Singh and Gu (2009) also list a set of support technical requirements, which are expected to facilitate BIM implementation in a project. However, the support technical requirements are not discussed in this paper because they are not related to visualisation and AR integration.

4. An integration framework for interfacing BIM servers with AR

The technical requirements for a BIM server as discussed in Section 3 highlights the urgent need for a new interface that can utilise the list of the requirements. Among the list of these technical requirements, the core is the enhanced support for inter-disciplinary building data representation, organisation and interaction. We propose the following integration framework for interfacing BIM servers using AR. AR enables a mixed reality design environment that supports both face-to-face and distant collaborations. In an AR environment, building information can be generated and represented as 3D virtual models; the models can then be viewed and interacted virtually, or extracted and inserted into the multi-disciplinary users' views of a real-world scene (i.e. the actual building site). With TUI, AR can also support tangible interactions with digital building information beyond the use of the computer screen, mouse and keyboard, to allow more intuitive interactions such as gestures and body movements that are commonly used in traditional collaboration scenarios. The coupling of BIM and AR can open up potential opportunities for exploring alternative approaches to data representation, organisation and interaction for supporting seamless collaboration in a BIM server.

A BIM server supports multi-disciplinary collaboration by providing a platform for direct integration, storage and exchange of information from all payers involved in a building project. A BIM server is a collaboration platform that maintains a repository of the building information, and supports the viewing, checking, updating and modifying of both the geometric and non-geometric data. The integration framework as shown in Figure 2 highlights the main elements and relationships when interfacing a BIM server using AR.

The first aim of the integration is to support a wide range of activities occurred during the building project collaboration including the viewing, checking, updating and modifying of building information whenever required, accurately, easily and securely. As shown in Figure 2, the BIM model server therefore will need to satisfy the three sets of technical requirements presented earlier in Section 3 including BIM model management related requirements, design review related requirements, and data security related requirements. The second aim of the integration is to facilitate different levels of collaborations within a building project, through an intuitive interface. As shown in Figure 2, the AR-interfaced BIM server will need to provide a *private space* for intra-disciplinary collaboration where users can interact with specific disciplinary building information. For example, AR-based techniques can be used to foster joint attention to details in 3D models being reviewed by members of distributed teams. The BIM server will also need to provide a *public space* for inter-disciplinary collaboration where users can interact with integrated building information across different disciplines. For example, AR can be used for coordination and integration of onsite construction data with the office-based BIM model for regular update and validation of the construction process.

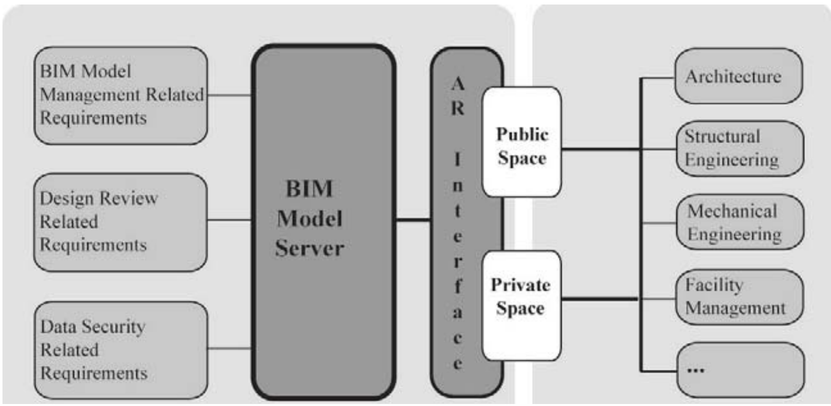

Figure 2. An AR interface for a BIM server.

5. Summary and future works

This paper emphasises the increased significance of realistic, accurate and intuitive visualisation for enhancing BIM-based collaboration across the different design and non-design disciplines in the AEC industry. The paper suggests that AR concepts technologies and techniques can be integrated with a BIM server to enhance visual communication and information exchange. The technical requirements of a BIM server as a collaboration platform are used as the basis to discuss a framework for AR and BIM integration. Such a framework is proposed (1) to support a wide range of activities that occur during building project collaboration including the accurate, secure and flexible viewing, validating, and modifying of building information, and (2) to facilitate different levels of collaborations within a building project, through an intuitive interface for intra and inter-disciplinary collaboration. The current extension of the project is to (1) detail the framework being developed with a design scenario to further explore different elements and their relationships outlined, and (2) prototype and trial an AR application as a BIM server interface to validate the framework.

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