International Journal of Technology 10(7): 1266-1275
ISSN 2086-9614

BIM INTEGRATION IN AUGMENTED REALITY MODEL

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(Received: November 2018 / Revised: December 2018 / Accepted: July 2019)

ABSTRACT

Building information modeling (BIM) is one of the most popular technologies contributing to information handling. However, the technology's contribution to fieldwork is very limited due to the limited interaction between the real and virtual world. Integrating BIM with augmented reality (AR) is believed to highly increase BIM's applicability to fieldwork. Therefore, the aim of the study is to examine the credibility of BIM integration into AR (AR–BIM) in the construction industry. A case study is adopted, computing the AR–BIM system through Structure Sensor, Unity 3D, and C#. The results show that BIM is compatible for integration with the AR platform. Although the preliminary AR–BIM system is not perfect compared to the marketed product, the initial investment cost of this system is much cheaper, while conserving the benefits of BIM in AR. This study is important to raise awareness among construction stakeholders about the adoption of technology. The stakeholders left out of the industrial revolution (IR 4.0) will lose their competitiveness in both local and international markets.

Keywords: Augmented reality; Building information modeling; Construction

1. INTRODUCTION

Advances in computing technology have allowed the construction of megastructures, limiting the industry's future development regarding information handling. In current practice, the construction of a structure is based on the drawings produced by architects and engineers. As a structure gets larger, the number of drawings involved increases accordingly. Besides, the task to detect the conflict between designs becomes more challenging when too much drawing is involved. Hence, information handling software is no longer an option, but mandatory for the AEC (architecture, engineering, and construction) industry. Varieties of CAD (computer-aided design) software have been introduced to the construction industry, not just to improve efficiency and accuracy, but to overcome problems that could hardly be handled previously. One of the most effective computer-aided platforms to manage information varieties is building information modeling (BIM).

BIM enters the picture when it demonstrates the ability to coordinate heavy and fragmented

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Permalink/DOI: https://dx.doi.org/10.14716/ijtech.v10i7.3278

information into a single model. BIM is not software, but it is a platform to integrate different information (software). Therefore, BIM is generally defined as a platform for digital presentation. It does not just allow the cross-disciplinary exchange of information, but also allows users to facilitate the interoperability of the whole project, detecting the conflict within (Chen et al., 2011; Eastman, 2018).

Although Construction Industry Development Board Malaysia (CIDB) had targeted Stage 2 BIM implementation by 2020 in the Construction Industry Transformation Programme (CITP) 2016–2020 (CIDB, 2007), the adoption of BIM in Malaysia's AEC industry is still worrying. Malaysia is reported to have only a 10 percent adoption rate, which is far lower than other countries', as the BIM adoption rate in the United States of America (USA), United Kingdom (UK), and Singapore relayed in the same report are at 71 percent, 39 percent, and 65 percent, respectively (CIDB, 2007). In the National Building Specification (NBS) International BIM Report 2016, the BIM adoption rate in Canada, Denmark, and Japan was 67 percent, 78 percent, and 46 percent, respectively, while the UK's adoption rate is reported to have undergone a significant increase of 10 percent in just one year. Malaysia is said to be amongst the lowest BIM adoption rate countries, compared to other developed and developing countries.

Undoubtedly, BIM will be a construction standard in the future. This can be observed from the enforcement of BIM in some developed countries. According to BCA (Building and Construction Authority) Singapore (2011), a few countries that made BIM one of the compulsory criteria for construction proposal submission are Hong Kong, South Korea, Finland, Denmark, the United Kingdom, and Norway (BCA, 2012). All these countries made compulsory the adoption of BIM, either in public projects, projects costs over certain amounts, or even all the projects in the country. In addition, Singapore in 2015 enforced the adoption of BIM in projects having a gross floor area of more than 5,000 square meters. The reluctancy to adopt BIM is that a business, especially contractors, might lose their competitiveness in local and international markets (Jóhannesson, 2009). Moreover, BIM is further enhanced to be integrated into green initiatives to reduce the carbon footprint, as highlighted in the Green Star (New Zealand), Green Building Index (Malaysia), Green Mark (Singapore), Leadership in Energy and Environmental Design LEED (US), and the BRE Environmental Assessment Method (BREEM, in Europe; Fathoni et al., 2015; Bahriye & Hakan, 2015; Amarnath et al., 2016; Liu et al., 2017; Dat et al., 2018).

As BIM implementation is foreseeable as a must in an industry, it is wise to plan ahead of current practices by integrating BIM into different disciplines. BIM is now extended from 3D to 4D (scheduling), 5D (costing), 6D (life-cycle information), and 7D (facility management). The BIM model presented on desktop devices is no longer suitable for serving different management purposes. Therefore, a study to integrate BIM with augmented reality (AR) was initiated to examine the credibility of AR–BIM in the construction industry.

2. BUILDING INFORMATION MODELLING AND AUGMENTED REALITY

The BIM model can be shared across multi-disciplinary professions and be used for illustration purposes during the entire building life cycle, from the inception and design stage until the operational and maintenance stage. However, the current contribution of BIM to fieldwork is very limited due to its limiting level of interaction between the virtual and real world (Wang et al., 2014). Most of the existing BIM is modeled on devices that do not accompany any sensory components, resulting in zero interaction between the model and the physical situation. Consequently, BIM can only serve as a visualizing tool in fieldwork. Thus, the introduction of another computing technology, AR, into the existing BIM system can help to overcome the problem, bridging the BIM model with the physical situation.

AR generates an environment where the virtual object or information from computers is superimposed on a real-world scene, resulting in a mixed world (Jiao et al., 2013; Chi et al., 2013). Current technologies allow the mixed world to be formed when users observe an object through specially designed head-mounted equipment or a mobile device. The display of the head-mounted equipment should comprise transparent material that allows the user to observe the real-world situation while looking at the display. In the case of a mobile device, the virtual object is shown together with the real-time image captured through the device's camera, forming a mixed world of two. One can then compare the real and virtual world, identifying differences with just a glance.

AR is an option for presenting BIM content. Conventional BIM provides a visual representation of building data through a workstation. The integration of AR enables a BIM model to be integrated into the real-world scene, which provides better illustration to the stakeholder. AR functions are normally emphasized during project execution phases, where a precise AR image can be brought to a construction site for verification purposes. Moreover, AR's abilities are appreciated in operation and maintenance stages, where AR is presented as underneath and embedded into the structures and components behind architectural finishes. Therefore, AR emphasizes productivity enhancement rather than visual image representation compared to traditional BIM.

2.1. Interoperability between BIM and AR

Integrating BIM with AR is one of the most popular ideas in improving the usability and applicability of BIM in fieldwork. However, there is a question about how these two technologies can be integrated. To the best of the authors' knowledge, scholars have proposed basically three main ways to integrate AR into BIM.

Tabletop AR–BIM is the simplest way to integrate the two technologies. The concept of AR technology is simple; it is just about registering and tracking markers. In tabletop AR–BIM technology, any engineering plan could serve as a marker, while the 3D BIM model produced from any BIM software would be used as the digital contents to be shown in these markers. When one mounts AR devices on top of the engineering plan, the corresponding 3D BIM model is displayed on devices. Besides, the tabletop AR–BIM utilizes motion tracking technology, in which the orientation of the BIM model changes accordingly when users move around the plan and are allowed a better visualization of the model.

Tabletop AR–BIM remained as an idea until SmartReality mobile applications were introduced by JBKnowledge in 2013 during Chicago's Associated General Contractors (AGC) of American IT Forum (PRWeb, 2017). The SmartReality mobile application allowed the users to overlay a corresponding 3D BIM model on top of building plans using any mobile devices, such as an iPad and smartphones. The users can manipulate the model either by zooming in and out or removing layers such as cladding from the model using the mobile application. SmartReality is very simple to utilize, as users are just required to upload their 2D drawings and 3D models to the web portal of SmartReality, and SmartReality will perform the pairing job for users. Once pairing jobs are complete, users can utilize the services by mounting applications on printed engineering drawings (Jones, 2014). Currently, there are few successful examples of utilizing SmartReality applications in construction. JBKnowledge showed two case studies on the official website of SmartReality, the use of SmartReality for the visualization of complicated parapet details by Hoar Construction, and the use of SmartReality for marketing visualization purposes by TURIS Systems, as shown in Figure 1.

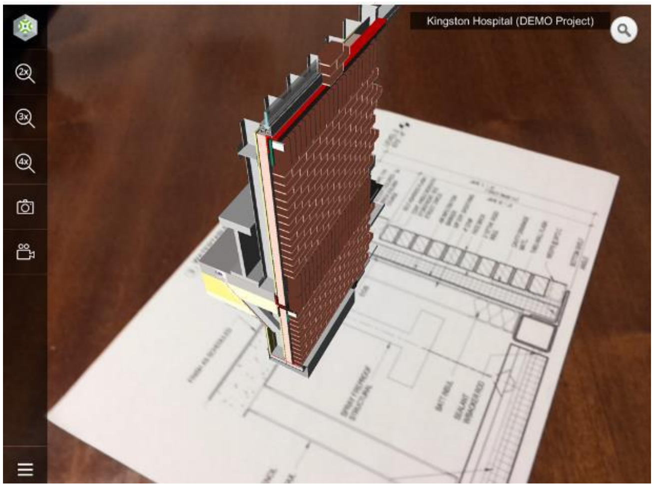

Figure 1 SmartReality product by Hoar Construction (Source: SmartReality, n.d.)

Portable AR–BIM is similar to the tabletop AR–BIM system. However, instead of tracking markers on drawings, portable AR–BIM tracks particular features on the scene captured. As an example, the information of a particular wall would be shown when one looks at it through the portable AR–BIM system. Besides, instead of showing the whole BIM model, a portable AR–BIM system only zooms into the corresponding part of the model when one is looking at a feature. In addition, the portable AR–BIM is similar to VR, where the movement and motion of the users will be tracked by the system and the digital contents displayed will change with these movements. Portable AR–BIM is much more suitable for use at a construction site, as it would not affects the user's view of the real-world situation.

The idea of a portable AR–BIM system was realized with the Daqri Smart Helmet in 2016. Although the Daqri Smart Helmet was first unveiled in early 2016 during the International Consumer Electronic Show (CES) 2016, there are no mentions of the use of the helmet in the construction field (Takeuchi, 2011). The use of the Daqri Smart Helmet in construction was only unveiled in late 2016, as the result of cooperation between Daqri Smart Helmet, Mortenson, and Autodesk (Daqri, 2013). The demo was conducted in November 2016 inside the HCMC Specialist Center. In the demo, Mortenson employees could see the detail of every element modelled in Autodesk BIM360 through the Daqri Smart Helmet. When they walk around, the digital contents shown will change accordingly. The information provided by the overlaid BIM model does not just allows users to visualize future development but also makes it a promising monitoring tool in construction sites.

As the Daqri Smart Helmet (see Figure 2) for construction had not yet debuted in the market, there is no review and other examples of utilizing the Daqri Smart Helmet at a real construction site. However, the Daqri Smart Helmet would be much more usable if it included artificial intelligence in the system, as shown in the Daqri Smart Helmet's demo during CES 2016. Besides, the demo only showed the visualizing ability of the helmet but left aside the sensing ability of the previous version of the Daqri Smart Helmet. Accordingly, the company should include all these technologies to improve the technology's usability at a construction site. Last, the information provided by the helmet seems to be very limited; it only includes geometric elements, not time or cost elements. The helmet would be much more usable if one could discern information about all elements and their expected construction time through the devices. In conclusion, even the Daqri Smart Helmet is much more practical than SmartReality at a construction site; there is still room for improvement for the device, as it is just for visualization and is much portable than the tabletop AR–BIM.

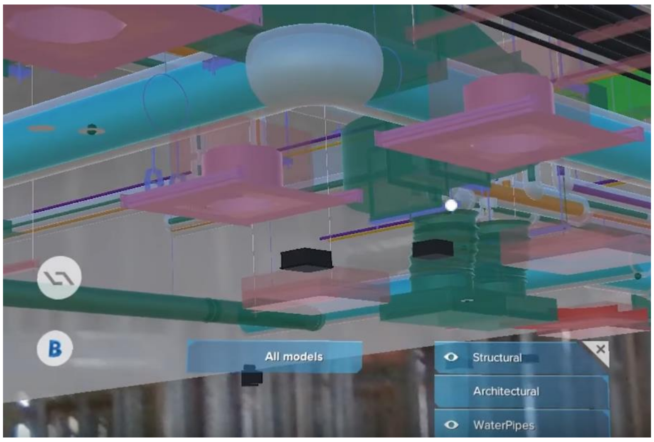

Figure 2 Daqri smart helmet by Mortenson (Source: Building the Worksite of the Future, 2016)

The concept of remote monitoring AR–BIM is varied, compared to previous types of AR–BIM. Users first record the videos on the site situation occasionally. While videos are recording, all the recorded parts will be sent to the office through the internet. The system in the office will then augment a layer of the BIM model on top of the real-world situation. One can then easily tell the difference between the real-world situation and the model. Besides, augmenting the model as planned on top of the constructed structure can help one to visualize the future development of the structure. Unlike tabletop and portable AR–BIM, which require users to be at the construction site to understand the site's situation, remote monitoring ARBIM allows users to monitor the site situation by just staying in the office.

Bentley partially realized remote monitoring AR–BIM in 2016 (Vrfocus, 2017). In the Bentley experiment, all the videos were captured using moving drones, and they were only sent to the office after they were finished being captured. Notably, this method differs from the concept of remote monitoring AR–BIM, where the videos had to be live. After the office received the videos, the mesh of the structure in the video was captured using context capture technology, which is aligned with the BIM model. After the BIM model was aligned with the real-world situation in every frame of the video, the system overlaid the BIM model on top of the structure in the video, resulting in the augmentation shown in Figure 3. Bentley's experiment showed the possibility of realizing remote monitoring AR–BIM in the future; it is just a matter of time. The benefits of this type of integrated AR–BIM is that it allowed users to monitor the site situation even when they are staying in the office, which is located a distance from the site.

Figure 3 Augmentation of drone videos for site monitoring (source: Bentley System, 2016)

There is still room for improvement, as every platform has its own benefits and limitations. For instance, tabletop AR–BIM seems to be the most promising marketing tool among the three, while portable AR–BIM is much beneficial to contractors and remote monitoring AR–BIM is much more suitable for use by developers.

3. SOFTWARE ARCHITECTURE

AR enables users to interact with objects (including modifying the scale, position, and other properties) that fit perfectly into the real environment. As such, many studies have argued that AR technology could provide new possibilities for interaction and promote an active learning experience. From the literature, it is discovered that the existing industry-functional AR–BIM user interface involves a huge development budget. Therefore, this study is taking the initiative to reduce the investment cost by developing a simpler method to perform AR–BIM in the construction industry. Figure 4 shows the software architecture of AR–BIM.

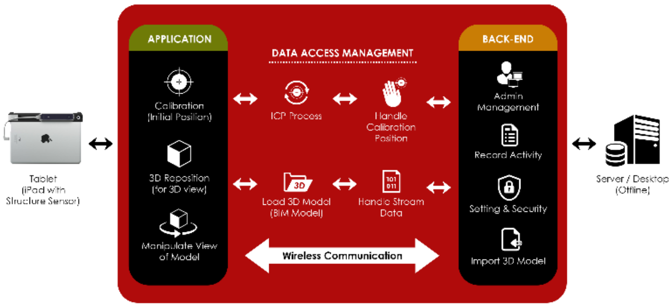

Figure 4 Software architecture of AR–BIM

The BIM model is the first export to Unity 3D. Unity 3D is a powerful 3D cross-platform engine and an easy-to-use development environment. Unity 3D has empowered several visual advancements. The graphical articulation of the augmented objects turned out to be more exact by utilizing Unity's built-in Shaders. Consequently, the augmented 3D model's appearance is practical, and the graphic alteration was fast with an on-the-fly play testing and modifying feature. Additional realistic handling effects can be depicted through Unity's built-in physics engine. Some added values are that, with Unity 3D, all the toolset highlights of Unity make composing code more instinctive. Designers observe the relationships between programming code and GAME OBJECTS outwardly. In addition, designers need not expect and alter values just by code; they can instantly check how an object responds through property changes. Moreover, the correspondence between the graphic part and programming part was smooth since Unity upgrades the connection between the two sections. These properties of Unity boosted the process of game development enormously. Unity 3D additionally underpins different formats, for example, MAX, MB, FBX, OBJ, permitting detailed and systemic interoperation with different programs (Kim, 2014).

Subsequently, the model is calibrated with a structure sensor. The Structure Sensor was developed by Occipital (2014). An open-source platform, it works as a mobile structure light system (SLS) when it is linked to a mobile phone, computer, or tablet. SLS consists of a laser-emitting diode, infrared radiation range projector, an infrared sensor, and an iPad's RGB sensor, which sends the information to a system on a chip (SOC) for processing. The device clips on the back of an iPad, allowing the user to perform 3D scanning for objects in real time (Hendrix et al., 2016). The scanning ability of a structure sensor allows Unity to coordinate the model by matching the virtual model (BIM) with reality 3D scanning (from the structure sensor).

4. RESULTS AND DISCUSSION

A maskless photolithography process was performed successfully using an infocus in114a dlp projector and applying dry film photoresists within established parameters of exposure time: four minutes, developing time: three minutes, etching time: two minutes, and removing time: one minute. Some products maskless photolithography process that successfully made such a flip-flop lamp, mini power supply, and alarm. The smallest pcb routing width produced is 100 µm ± 5 µm.

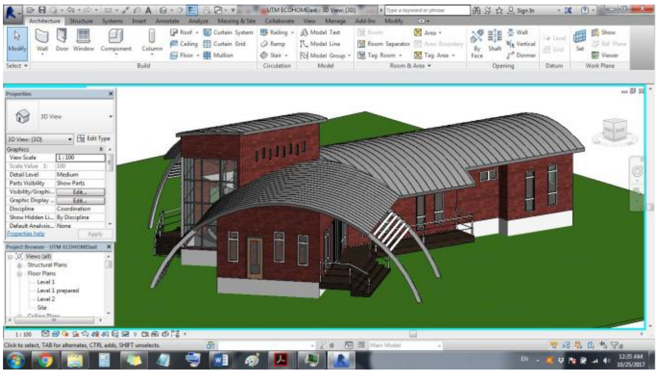

Figure 5 Case study's BIM model

The case study is a 1.5-story-tall residential building. The floor plan of the building is shown in Figure 6.

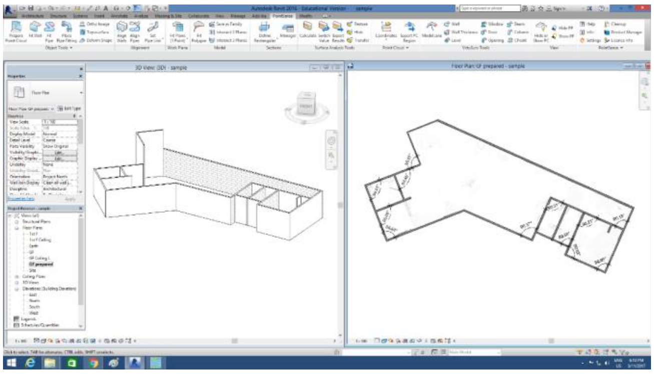

Figure 6 Floor plan

The BIM model consists of all-around architecture, civil, structure, mechanical, and electrical information for the case study. However, the AR–BIM prototype adopted architecture information only for preliminary development. During the coding and data management process, the AR–BIM prototype is presented in semi AR form, as shown in Figure 7. By providing the superimposed geometric representation on the physical space along with the relevant information in real time, AR provides a suitable interface to support field work.

Figure 7 shows that the reality model is not presented in devices, which can be improved through C# on the Unity platform. The device shown is a wholly virtual model, integrated successfully in terms of virtual model location identification (coordinate of the virtual model and actual building, x–y–z axes). Location identification is important for locating the user in the building. This is done through C# on the Unity platform.

Figure 7 Inner view of the building

The case study discloses the potential benefits of AR–BIM from three (3) perspectives.

1) The first usage of AR–BIM is as a project inspection tool. Engineers no longer needed to bring A1-sized drawings to project sites for inspection purposes.
2) The second usage of AR–BIM is facility management. The facility management team can easily identify the inner piping (both electrical and plumbing) without referring to complicated as-built drawings.
3) The third usage is training purposes. AR–BIM allowed the project to be documented in the database. This is important for the high turnover rate in the construction industry, whereby newcomers can be trained from the archived AR–BIM documents. The training might involve engineering inspection procedures, safety, forensic inspection, and others.

Regarding BIM-specific use cases, three are the most prominent and provide value to organizations: conveying real-time maintenance information, increasing the efficiency and accuracy of plans in the field, and easing collaboration between key project members when drawing up construction plans. Concerning AR–BIM real-time maintenance and inspection, the data visualization provided through AR is one of the most useful use cases. Specialized hardware and software kits, like Daqri, allow users to investigate a BIM-mapped building's walls to identify water pipes, wiring, HVAC components, and more. For massive buildings and facilities, this technology is ideal for tracking down specific utilities for routine maintenance, replacement, or the addressing of issues if problems occur. Looking through a visor is much more intuitive than relying on conventional building plans or blueprints. Additionally, these kinds of products allow information to be updated in real time, enabling maintenance workers to log detailed notes or descriptions. Another arena where AR is helping push forward BIM is on the job sites of projects that have begun construction. With just a tablet or a smartphone, engineers, laborers, and supervisors can visualize elements of a project on demand. This ensures that collaboration between different on-site disciplines, like electrical and plumbing, can communicate and collaborate clearly and effectively. With BIM-backed AR apps, questions about what materials are being used, where, or how something should be installed are addressed before problems or conflicts arise.

When users are collaborating with people, clients, or those not necessarily from engineering or construction backgrounds, this kind of visceral and immersive experience helps to convey concepts that would otherwise be hard to express through conventional means. A study shows that 63% of participants believe that AR can facilitate the earlier detection of problems at the design stage (Poorang et.al, 2017). This can serve as a strong driver for the implementation of these technologies into the design phase of a project. Although the applications of VR are more evident than AR, this may be due to users being more familiar with VR compared to AR. The study suggested that 3D modeling is an unnecessary complication, AR technology being most suitable to medium-sized projects. The reason for this could be that AR systems have probably become more powerful, smaller, more reliable, and more portable since 2010. However, current opinions indicate that systems are still not powerful enough to be utilized in the industry as easily as they could be and efforts are being made to introduce a system such as AR–BIM into the construction industry (Poorang et. al, 2017).

5. CONCLUSION

BIM has made limited contributions to fieldwork due to its limiting interactions between the real world and virtual world. However, the integration of AR into a BIM system provides a platform for interaction to be achieved. An AR–BIM system allows the relevant personnel to obtain feedback immediately by just mounting mobile devices on constructing elements. The difference between modeled information and on-site information of those particular elements and all the interdependent elements will be compared in the AR environment, showing the difference immediately. The AR–BIM-integrated system is less time consuming, as users are not required to access the whole BIM model, just to extract the information of one component when mounting the device on it.

The proposed AR–BIM system is relatively affordable compared to the other three methods mentioned in section 2. By considering the cost of an app designer and BIM model computation as a constant, the cost of a structure sensor is $500, whereby the other three methods could not make it with this budget. The construction industry has given the impression that it is outdated, and stakeholders are reluctant to invest, especially in innovative technology devices. Therefore, the proposed AR–BIM system is designed to reduce the initial investment cost while conserving the benefits of AR in BIM integration.

6. ACKNOWLEDGEMENT

The work is supported by FRGS (HM102600), Ministry of Education, Malaysia.

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