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BIM AND VR/AR TECHNOLOGIES: FROM PROJECT DEVELOPMENT TO LIFECYCLE ASSET MANAGEMENT

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Building Information Modeling (BIM) is becoming more and more an industrial standard for the AEC industry that can provide an integrated approach for effectively managing data and information throughout a project lifecycle. Planning, design, and construction phases of different types of projects can benefit from integrating other technologies such as Virtual Reality (VR) and Augmented Reality (AR) with BIM to enhance its functionalities, including virtual walkthrough, schedule visualization, clash detection, and as-built modeling. Additionally, asset management functions during the maintenance and operation phase of facilities and infrastructure can substantially benefit from this kind of integration. This paper will provide a comprehensive review upon several emerging technologies regarding (1) technological advancements reflected by software and hardware development, (2) applications in the design, construction and asset management through integration with BIM in all phases of projects, and (3) current state of research and practice. It will specifically, provide some limiting factors that prevent VR/AR from further deployment, including lack of GPS accuracy, complexity in development and unclear data security will be explained. Additionally, this paper will present the benefits of integrating VR/AR technologies with BIM throughout the project lifecycle.

Keywords: Building information modeling, Project lifecycle, Emerging technologies, Geographic information system, Internet of things, Cloud technology, Challenge.

1 INTRODUCTION

The construction industry involves multiple stakeholders with data-intensive processes where generated data need to be coordinated and kept up to date throughout the life cycle of the project. With low productivity and less sustainable practices, construction industry was driven to adopt building information modeling (Froese 2010). Building Information Modeling (BIM) is an intelligent model-based process that provides insight and tools to plan, design, construct, and manage buildings and infrastructure more efficiently (Autodesk 2019). Although BIM was introduced in the early ’80s and widely adopted since 2000, the construction industry still faces significant challenges in implementing BIM, such as high costs of software licenses, difficulties of managing project files from multiple sources, and long learning curves for senior practitioners (Bråthen and Moum 2015, Vonsovicz *et al*. 2018). While exceling in providing product-oriented solutions, BIM has not been effective in addressing the needs of a common platform for all stakeholders to communicate and exchange information to achieve collaborative decision-making (Eadie *et al*. 2013, Alreshidi *et al.* 2016). In response, BIM with Geographic Information System

(GIS), Cloud BIM, BIM with Internet of Things (IoT), and BIM with Virtual Reality (VR) and Augmented Reality (AR) are some of the enhanced technologies, which improve BIM's capabilities to provide process-based solutions.

2 BIM-RELATED TECHNOLOGIES

2.1 BIM with GIS

Geographic Information Systems (GISs) have made it possible to visualize, question, analyze and interpret spatial information, edit data in maps, and present the results to create interactive queries and understand relationships, patterns, and trends (Clarke 1986). BIM helps to manage and share the lifecycle data of any infrastructure facilities while GIS helps to capture, manage, and evaluate the geospatial data of the urban environment (Ma and Yuan 2017). The integration of BIM and GIS is essential in many applications where data of both sources are required.

In the planning and development phase of a project, by importing BIM models into the geospatial environment, site selection for buildings based on their functionalities can be done; structural design, interior and acoustic design, energy modeling of facilities can be made much more accurate; and traffic design, climatic assessment, design authorization, and performance evaluation can also be performed (Ma and Yuan 2017). Integrated applications on infrastructures by using road construction data from BIM models and topographic data from GIS databases allow earthwork simulation, schedule management, and walkability analysis. During the construction phase, integration of BIM and GIS has been used not only for the construction of new buildings but also for the retrofit of old buildings. BIM is used to get a detailed takeoff in the early procurement phase and GIS is used to perform geospatial analysis, which helps supply chain management and schedule management. Importing as-is geometric BIM data and other necessary data into GIS helps in the preparation and decision-making of building retrofit projects (Niu *et al*. 2019). Operation and maintenance (O&M) of buildings requires a level of data integration. Having architectural information from BIM models and historical semantic information from GIS databases in a single platform helps in heritage protection. Risk assessment using integrated GIS and BIM model helps in hazard response and risk management, energy management, space navigation, and facility management (Kang and Chang 2015). Compared to only using BIM tools, the integrated BIM-GIS method enables the geospatial analysis, making possible waste assessment, categorization, logistic management, and many other applications involved in rehabilitation megaprojects (Kim *et al*. 2015).

2.2 BIM with IoT

Internet of Things (IoT) is defined as the interconnection of sensors and actuators to share information across platforms to develop a common operating platform (Liu and Lu 2012). Connecting BIM and IoT provides enhanced views of the project that collectively complements the limitations of each other, as BIM models offer most accurate digital representations of as-designed buildings while IoT captures real-time data from actual construction and operations of the facility (Tang *et al*. 2019). During the construction phase, BIM and IoT devices like Radio Frequency Identification (RFID) tags are effective tools for manufacturing, logistic, tracking, and visualization of prefabricated components, since RFID enables the user to capture real-time information about the components and make prompt analysis for decision support purposes (Li *et al*. 2018). BIM serves as a useful tool in facilitating the on-site assembly services (OAS) of prefabricated construction. During the construction phase, remote monitoring of construction is possible by combining BIM and IoT, and early warning systems by employing GPS receivers to capture location information of large construction equipment with BIM model helps in conflict analysis and construction equipment management (Isikdag 2015). Low energy sensors on equipment and workers help to monitor the resources and provide timely instructions to equipment operators. On-site data collection using cameras and laser scanners (point clouds) can be integrated with BIM models to measure the construction performance and progress monitoring automatically (Lee *et al*. 2009). Sensors and BIM integration also helps to improve safety on site by alerting the workers against the hazard (Lee *et al*. 2009). Similar to the use scenarios during construction and fabrication, for facility management purposes, assets can be tracked in real-time using sensors on the physical components linked with the asset in the BIM model. Condition and performance of equipment can be continuously tracked to perform preventive maintenance. Monitoring the indoor environment quality is another important application of the technology (Fang *et al*. 2016).

2.3 Cloud-based BIM

Collaboration among teams with different skillsets from different organizations across the world is a challenging task. To address this issue, web-based technologies have gradually gained popularity in construction project management applications, helping to achieve the integration of planning, organizational, execution, and management aspects of construction projects. Virtual organizations enable users to work in their own workspace and provide the flexibility to work from any physical location (Cheng *et al*. 2012). Collaborative solutions in most construction organizations are hosted on their local servers, which limits the remote access to the hosted BIM data and increases data center management cost for maintaining and upgrading data repository facilities. Cloud computing-based BIM has advantages like high accessibility, storage scalability, and high-performance computing capabilities over conventional server-based BIM. Most cloud-based solutions are proprietary, with access to data depending on the company that provides the service (Alreshidi *et al*. 2016).

Complex data generated during the lifecycle of construction project can be effectively managed using BIM, but issues like data loss, data duplications, data inconsistency are inevitable when different stakeholders maintain respective databases. With cloud-based technologies, collaborative BIM among multi-discipline and multi-actors helps to tackle most of these data-related issues across a building's lifecycle (Alreshidi *et al*. 2017).

3 BIM WITH VIRTUAL REALITY AND AUGMENTED REALITY

Virtual reality (VR) creates a complete imaginary environment whereas augmented reality (AR) superimposes digital information over the existing environment (Rubio-Tamayo *et al*. 2017). Currently these visualization techniques have fewer applications in Architecture, Engineering, and Construction (AEC) sector compared to the manufacturing, medical operations, military, and gaming sectors, but are gaining momentum in all phases of the life cycle of buildings and infrastructure. VR/AR technologies are typically not stand-alone tools; they are used in conjunction with other technologies like GIS, IoT, and cloud computing (Chi *et al.* 2013). One example of such an integrated use is the visualization of prefabrication and/or construction processes through VR using real-time data captured through IoT and cloud computing.

Constructability analysis using BIM has not been successful because of the lack of communication among stakeholders participating from different geographical locations. Virtual Design and Construction (VDC) processes using VR enables users to digitally navigate through the digital BIM model, which helps to bring together all the stakeholders from remote locations. By walking through the 4D-BIM (3D BIM and schedule) model in VR, constructability analysis contributes to productive and efficient planning of a project (Du *et al*. 2018). VR is also an effective tool for safety training. With increasing migratory workers, it is essential to introduce the visual-based safety trainings on construction site as an upgrade to conventional training using demonstration and/or video presentation. VR simulations are used to train labor and make them aware of the project surroundings. Statistics shows that labor trained by VR perform better in identifying risks than those trained traditionally during the training period by 20% (Sacks *et al.* 2013). VRTEX, a VR welding training system, helps trainees to learn 23% faster than usual and develop better muscular memory and motoric patterns (Postlethwaite 2012). VR simulators for equipment operators are also great tools to improve the skill and efficiency of equipment operators (Tatić and Tešić 2017).

Augmented Reality (AR) applications simplify certain construction activities and reduce the cost and time spent on that activity. Layout marking, excavation, positioning and placing precast elements can be done by combining BIM with AR. AR headsets aid the users on site to view the BIM model over the real-world environment, which eliminates the need of on-site access to paper or digital drawings and specifications (Shin and Dunston 2008). It is concluded that construction workers using BIM with AR were able to complete the same task twice as fast as other crew using paper drawings (Chu *et al.* 2018). Inspections can also be made easier, faster, safer, and less expensive using AR along with intuitive equipment and connected intelligence, which can accurately track inspectors' location as they move around job sites (Zaher *et al*. 2018). AR-based inspection of tunnel construction reduced the overall inspection time by 25% (Zhou *et al.* 2017). With enough mobile computing capabilities, inspectors can also add photos or virtual notes that stick to a location and can be shared across multiple devices. Using imagery data with geo-tags, as-built models using photogrammetry techniques (Golparvar *et al*. 2009) can be created in the same digital environment with as-planned BIM models, making progress monitoring much easier (Wang *et al*. 2013). Laboratory for Interactive Visualization (LIVE) at university of Michigan created their own AR system for damage assessment of assets and remote operation of equipment. For O&M purposes, AR can be used to visualize layers of BIM to look through walls and inspect utilities. Facility operation by using AR enables the user to get information about the asset, failure information and the instructions to fix the failure (Koch *et al*. 2014).

4 SUMMARY AND CONCLUSION

This paper presented a review of BIM and related technologies with an emphasis on virtual and augmented reality. It was found that the recent advancements in BIM and related technologies, especially in AR, can overcome the difficulties of accessing to BIM models in construction field. The conventional issue of lack of reliable and accurate GPS regarding AR has also been gradually addressed, latest systems achieving the accuracy of 1 cm even in indoor environments.

The review also shows that the main drive of VR adoption is for visual support, whereas AR has shown much more potential in broader applications. The ability to track user location and movements makes AR a perfect tool for planning, layout, and inspection. AR headsets have become more compact over time and contemporary mobile devices have more powerful hardware to support AR applications. Industrial practitioners and researchers have made continuous effort in addressing issues associated with AR such as dependence on wired devices, restricted field of view, heavy weight of devices, accessibility issues, and affordability. Table 1 shows the year in which major research and development of AR/VR in civil engineering was published. It is noteworthy that new research over the past few years is almost stagnant, partly due to the advancement in commercial AR hardware that reduces research needs. Yet there are still unanswered questions that are preventing VR/AR from broader applications, including the benefits of using the technology under various scenarios, occupational health and safety concerns associated with prolonged device wearing, life cycle benefit and cost analysis of the technology, and integration of VR/AR with other disruptive technologies such as machine learning and artificial intelligence. Addressing these research gaps in future is expected to greatly promote the adoption of VR/AR in the AEC industry, thusly facilitate the development of BIM technologies and practices.

Table 1. Major research and applications of AR/VR in civil engineering.

Years	ScienceDirect	ASCE	Major Development	Major Research Area
Before 2000	9	1	Training simulations	Aero space, Advertisement
2000 - 2005	18	11	Architecture Model Visualization	Mobile AR
2005 - 2010	47	44	Engineering education, Employee training	Using AR to geolocate the photogrammetry points
2010 - 2015	138	66	VDC, Site Survey and Inspection.	Occlusion, Markerless AR, GNSS, and BIM with AR
2015 - Now	101	51	Asset Management	Point clouds with AR

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