ITcon

www.itcon.org - Journal of Information Technology in Construction - ISSN 1874-4753

A REVIEW OF CLOUD-BASED BIM TECHNOLOGY IN THE CONSTRUCTION SECTOR

SUBMITTED: August 2014
PUBLISHED: September 2014 at http://www.itcon.org/2014/16
GUEST EDITORS: Wang X., Li H., Wong J. and Li H.

Johnny Wong, Assistant Professor
Department of Building and Real Estate, the Hong Kong Polytechnic University, Hong Kong
E-mail: johnny.wong@polyu.edu.hk

Xiangyu Wang, Professor, Woodside Chair
School of Built Environment, Curtin University, Australia
E-mail: xiangyu.wang@curtin.edu.au

Heng Li, Chair Professor
Department of Building and Real Estate, the Hong Kong Polytechnic University, Hong Kong
E-mail: heng.li@polyul.edu.hk

Greg Chan, Postdoctoral Fellow
Department of Building and Real Estate, the Hong Kong Polytechnic University, Hong Kong
E-mail: greg.chan@connect.polyu.hk

Haijiang Li, Senior Lecturer
Cardiff School of Engineering, Cardiff University, UK
E-mail: LiH@cardiff.ac.uk

SUMMARY: *Cloud computing technology is regarded as a major transformational force that is causing unprecedented change across the communication and business disciplines. In the architecture, engineering and construction sector, cloud-BIM integration is considered to be the second generation of building information management (BIM) development, and is expected to produce another wave of change across the construction industry. Despite this, few studies to date have attempted to summarise the research literature on cloud-BIM. This paper explores the literature to identify the substantive work on cloud-BIM, particularly regarding building life cycle management, to provide valuable insight for practitioners and to propose avenues for further research. Thirty academic sources, including refereed journal articles and conference papers, were retrieved and analysed in terms of their research focus and nature of application. The review revealed that most cloud-BIM research has focused on the building planning/design and construction stages. The findings suggest that more research should be directed towards operation, maintenance and facility management, energy efficiency and the demolition and deconstruction stages of building life cycle management. Further empirical research on organisational and legal issues, including security, responsibility, liability and model ownership, of the cloud-BIM model is also needed.*

***KEYWORDS*:** *Cloud computing, BIM, construction sector, building life cycle*

REFERENCE: *Johnny Wong, Xiangyu Wang, Heng Li, Greg Chan, Haijiang Li (2014). A review of cloud-based BIM technology in the construction sector, Journal of Information Technology in Construction (ITcon), Special Issue BIM Cloud-Based Technology in the AEC Sector: Present Status and Future Trends, Vol. 19, pg. 281-291, http://www.itcon.org/2014/16*

1. INTRODUCTION

While building information management (BIM) and visualisation technologies continue to evolve the traditional practices of the architecture, engineering and construction (AEC) sector (e.g. the works of Li et al., 2008; Baldwin et al., 2009; Dunston and Wang, 2005, 2011a&b; Wang and Dunston, 2011; Park et al., 2013; Wong et al., 2014a&b) and oil and mining industry (e.g. the works of Hou et al., 2014a, and Wang et al., 2014), promising innovations such as cloud and mobile technologies are expected to initiate the next wave of technological development, which will transform the construction industry to the next level of technological advancement (Anumba and Wang, 2012a&b; Wang and Dunston, 2012; Wang et al., 2013). A recent report by McGraw Hill Construction (2014) revealed that the adoption of BIM in a construction project not only helps to enhance collaboration amongst the project stakeholders, but also leads to a positive return on the investment in BIM by reducing errors and omissions. At the same time, however, BIM has been criticised as a standalone system framework that restricts project stakeholders' access to a common set of data or information (Chunag et al., 2011). The initial investment cost of a BIM system is also high (Kim, 2012). The emerging cloud-BIM technology is considered an enabling tool that can deal with the standalone nature of traditional BIM. It can lead to higher levels of cooperation and collaboration, and provide an effective real-time communication platform for project team members. To date, there has been no review of the existing developments and research into cloud BIM. Therefore, the comprehensive review presented in this paper is of great benefit, particularly in identifying where more efforts are needed and identifying future research directions. This review of scholarly works also provides valuable insight to the industry professionals and BIM developers involved in the implementation of cloud-BIM. The aims of this paper are 1) to provide an inclusive literature review of state-of-the-art cloud-BIM technology research and its implementation in building life cycle management, and (2) to identify and highlight the current trends and research deficiencies in this area. This paper is organised into the following sections. First, the terminology of cloud computing is discussed in the Section 2. Then, the literature review method and the literature sources are presented in Section 3. The state-of-the-art cloud-BIM development and scholarly research works are summarised and discussed in Section 4. Finally, the research gaps and further studies are discussed and the conclusion is presented in Section 5.

2. WHAT ARE CLOUD COMPUTING AND CLOUD-BASED BIM?

Cloud computing is a rapidly emerging technology that can be used by communication devices such as PCs, tablets and smart phones. Although the concept of cloud computing was introduced in 2004 (Vouk, 2008), awareness of it has increased since October 2007, when IBM and Google announced a cloud collaboration project (Lohr, 2007). Vaquero et al. (2009) found more than 20 definitions of cloud computing, among which the definition provided by the National Institute of Standards and Technology (NIST) (Mell and Grance, 2011) is the most widely recognised. According to NIST, cloud computing is a model for 'enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g. networks, servers, storages, applications and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction'.

The architecture of cloud computing consists of four layers (Zhang et al. 2010): *application, platforms, infrastructure* and *hardware* (from top to bottom). The hardware layer consists of the cloud's physical resources (i.e. computer equipment such as servers). The infrastructure layer is also known as the 'virtualisation layer' because it uses virtualisation technologies to manage computing resources by partitioning physical resources. The platform layer consists of operating systems and application frameworks that reduce the burden on the virtual machine, and thus acts a kind of virtualised server. The top layer is the application layer, or the actual cloud application. These layers are loosely coupled so that each layer can evolve separately (Zhang et al. 2010).

There are various ways of classifying cloud computing technology. According to Kang et al. (2008), cloud computing can be divided into three main categories: private clouds (used by generating services with private IT assets), public clouds (IT proprietary rights are expanded to external with business of service provision) and mixed clouds (a hybrid of private and public cloud systems). In addition to these three deployment models, Mell and Grance (2011) suggested a community cloud model. A private cloud is used exclusively by a single organisation comprising multiple consumers. A community cloud is used exclusively by a specific community of consumers from organisations with shared concerns. A public cloud is an open access cloud that the general public can access. A hybrid cloud is an infrastructure that comprises two or more cloud deployment models (e.g. private, community and public). NIST defined three service models and four deployment models of cloud computing (Mell and Grance, 2011). These models provide different business opportunities for different organisations as they can be combined in various ways. Organisations can choose the right combination that suits their needs when moving to the cloud environment, as the service models and deployment models have different advantages and drawback. The three types of service models are 1) Software as a Service (SaaS), 2) Platform as a Service (PaaS) and 3) Infrastructure as a Service (IaaS) (Mell and Grance, 2011). SaaS is a service that allows users to use a software application over the Internet by connecting to the service provider through a browser. Examples of SaaS include Salesforce.com, Rackspace Google Doc, Google app, Yahoo mail and Microsoft Office Live (Zhang et al. 2010; Bhardwaj et al., 2010; Tao et al., 2011). SaaS is suitable for small businesses as the service provider maintains and manages the software and hardware (Zhang et al. 2012). PaaS users can develop their own applications and transfer them to other clients via the Internet. The advantage of PaaS is that it allows end-users to develop their own applications, libraries and tools to support their services using programming languages. Zhang et al. (2010) and Tao et al. (2011) listed a few PaaS examples, such as Google App Engine, Force.com, 800App and Mircosoft Azure. With IaaS, the service provider provides only the hardware such as storage, virtualisation and processing capacity. End-users only pay for the hardware and can deploy the software to provide services for their clients. IaaS can dramatically decrease the hardware cost for end-users (Mell and Grance, 2011). Examples of IaaS include Amazon's EC2, GoGrid's Cloud Servers, Joyent and Flexiscale (Zhang et al., 2010; Tao et al., 2011).

Cloud computing technologies have been widely adopted by different industries in recent years. Razak (2009) suggested using cloud computing technology to improve teaching and learning in Malaysian universities. Ercan (2010) reviewed cloud computing and explored its use in educational institutions. Khmelevsky and Voytenko (2010) developed the infrastructure prototype for using cloud computing in university education and research. Regarding the use of cloud computing in the health care sector, Stein (2010) argued that the time was right for genome informatics to migrate to the cloud. Rolim et al. (2010) suggested using cloud computing to collect patient data in health care institutions, while Doukas et al. (2010) suggested that the data could also be managed by cloud computing. Li et al. (2013) suggested sharing personal health records and Rosenthal et al. (2010) proposed that information could be shared among the biomedical informatics community via cloud computing.

3. REVIEW OF CLOUD-BIM TECHNOLOGY DEVELOPMENT IN THE CONSTRUCTION FIELD

3.1 Methodology

The two-stage literature review method was adopted to identify journal articles that describe and investigate the use of cloud-BIM technologies in the construction field, published in refereed journals, conference proceedings and other scholarly publications. First, a comprehensive literature search based on the 'title/abstract/keyword' search method was conducted using the Scopus, SCI and Google Scholar. The search keywords included cloud-BIM, cloud computing in construction, etc. Papers with these specific terms included in the title, abstract or keywords were selected as possible publications. A more focused and comprehensive search was then conducted with the support of the search engines. Articles (journal and conference) and review papers were included, while editorials, book reviews, letters to editors, discussions/closures and comments, etc. were excluded. Finally, a total of 30 cloud-BIM related papers were identified and included in the literature review. Several recent trends were obvious:

- Cloud-BIM is a new research area in construction IT studies. The earliest publication on cloud-BIM was published around 2010/11, and the number of publications has continued to grow since then.
- The 30 publications and relevant standards (excluding Internet sources) directly related to cloud-BIM comprised 15 journal papers, 7 conference papers and 8 other publications (e.g. books or papers in applied journals). Many of the journal articles were published in the journals *Automation in Construction* and *Journal of Information Technology in Construction (ITCON).*

3.2 An overview of cloud-based BIM research

The integrated cloud-BIM model, considered to be the second generation of BIM, enables higher levels of cooperation and collaboration and a more effective real-time communication platform for project team members (Figure 1). However, the technology is still relatively new to the construction industry. Redmond et al. (2012) carried out semi-structured interviews with 11 experts to discover how the information exchange process could be improved by the use of cloud BIM. They concluded that cloud-based BIM could create opportunities for different disciplines to share and exchange the necessary data for making key decisions at the early design stage. Porwal and Hewage (2013) suggested that the integration of cloud computing with their BIM partnering framework could facilitate the pre-planning of sustainable construction throughout a project's lifecycle. However, Chong et al. (2014) reviewed six cloud-based BIM systems, Autodesk BIM 360, Cadd Force, BIM9, BIMServer, BIMx and Onuma System, and found that only three of these systems supported private clouds and only two recognised IFC files. Chong et al. (2014) further maintained that current cloud-based BIM software may not be suitable for small contractors and only five types of software suit the needs of large contractors.

Some cloud-BIM studies have focused on the development of deployment models or frameworks. Kumar and Cheng (2010) reviewed cloud computing technology and suggested a framework for the implementation of cloud computing for information sharing in the construction industry. They found that interoperability is the key to the success of cloud implementation. Chuang et al. (2011) suggested integrating an SaaS-based visual cloud system with BIM for BIM visualisation and manipulation, although they did not provide details of the system's deployment model. Juan and Zheng (2014) developed a framework that integrated BIM with hybrid cloud deployment and described how the system could be applied in a real construction project. Meza et al. (2014) developed a BIM-based augmented reality system and used a cloud computing environment in the data phase. However, cloud computing was only used as a platform to share information and the study did not provide details of how cloud computing was implemented.

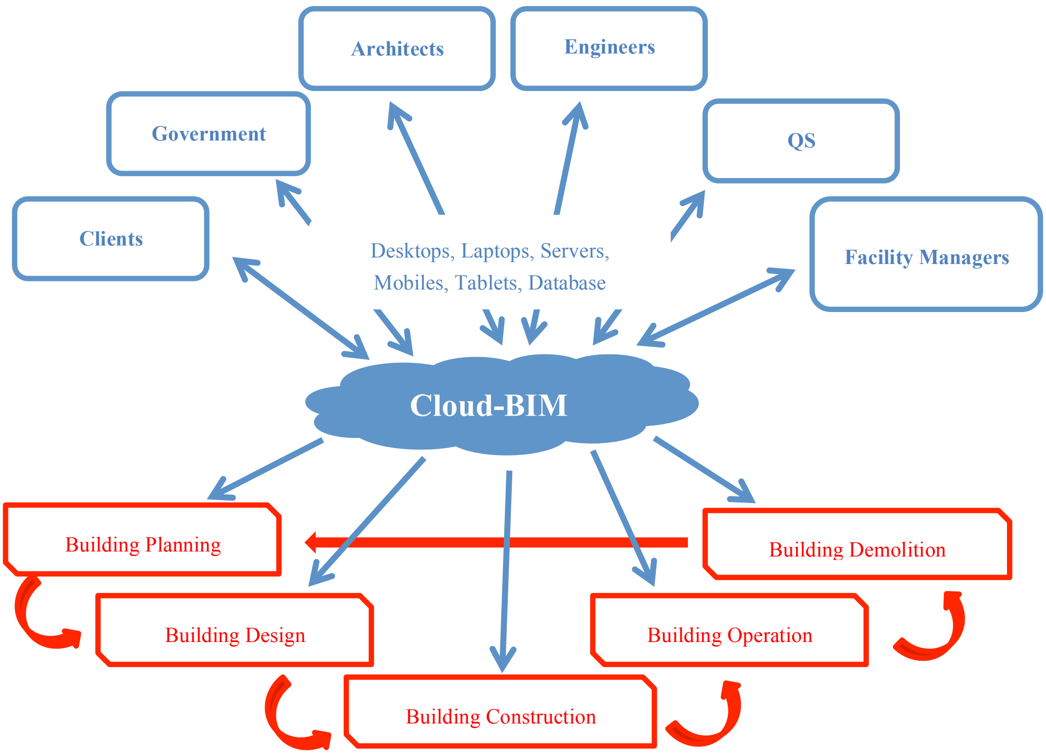

FIG. 1: Cloud-BIM Concept

Some researchers have tried to apply and test the technology in the real construction world. For example, Wu and Issa (2012) integrated BIM and cloud computing to automate the Leadership in Energy and Environmental Design (LEED) process for green building certification. They proposed the use of cloud services from different service providers (such as STRATIS, a private cloud server for Autodesk Revit) to achieve LEED automation. Sawhney and Maheswari (2013) proposed a framework for tracking the history of design information in cloud-based BIM. Grilo and Jardim-Goncalves (2011) integrated BIM with cloud computing, a model-driven architecture and service-oriented architecture for e-procurement in the AEC sector. They developed the SOA4BIM framework and validated the performance of the system during the conception and design phases. The SOA4BIM system includes three platforms: i) Microsoft SharePoint 2007 (for implementing a workflow and rule-based procedures); ii) EDM Model Server (for BIM data management); and iii) Vortal eGOV (for e-procurement) (Jardim-Goncalves and Grilo, 2010). In the building design stage, state-of-the-art BIM software provides support for various types of building design analyses, for instance by providing information in the early design stage about the design and selection of building materials and mechanical systems through integration with energy performance analysis software. Cloud computing technology offers an effective way for a design team to share building data and check real-time energy performance, regardless of physical location. During the construction phase, the current BIM model helps to track the construction progress, coordinate construction schedules and detect potential clashes due to design errors. Cloud-BIM technology can provide real-time monitoring of construction progress, coordination, clash detection and data sharing amongst the construction team, regardless of physical location. However, one may observe that most of these applications focus on the design and construction phases of the building life cycle.

Jiao et al. (2013) proposed a cloud-based BIM tool for lifecycle data management in the design, construction and facilities management of the Shanghai Centre in China. Autodesk Revit was adopted for the development of the first cloud-BIM model during the design phase of this project. The BIM model was then transferred to another format (LBIM format) and imported to the cloud platform. An SaaS model was used in this case. The cloud-based BIM was then used during construction phrase, and all 72 models were revised 56 times through the platform. At the end of the study, it was concluded that the use of cloud-based BIM could help to accelerate the construction process and reduce the cost (Jiao et al., 2013). Despite this positive outcome, it was also reported that some data were lost during the process of transferring the BIM model to the cloud server. Jiao et al. (2013) also suggested that cloud-based BIM can be used for lifecycle data management, although no detailed validation work was conducted.

As the concept of cloud computing is novel to the construction industry, only a limited number of scholarly works were identified in the literature. One of the observations is that the current application of cloud-based BIM is centred on the building planning/design and construction phases, while its application in the operation, maintenance and facility management, energy efficiency and demolition and deconstruction stages are overlooked. Although Jiao et al. (2013) suggested that cloud computing is a useful tool for managing data during the lifecycle of AEC and facilities management, they did not provide further details. Another problem with existing cloud-BIM research is that very few studies have evaluated its effectiveness. While some form of evaluation has been conducted by, for example, Jiao et al. (2013), there is a lack of detail about the evaluation methods and how the evaluations were conducted. A structured methodology for evaluating cloud-based BIM should be developed in future studies.

4. DISCUSSION AND FUTURE RESEARCH

The literature review revealed that most of the research efforts into cloud-BIM have centred on the building design and construction phases. For the building operation/maintenance and facility management stage, the conventional BIM model provides visualisation, access to the precise location and relationships between building systems and equipment, automated creation of equipment inventory lists and access to accurate information on existing conditions (Starkov, 2014). Cloud-BIM could be extended to provide an efficient means of identifying facility maintenance requirements, quick and real-time access to original equipment manufacturers and building maintenance records. It could be also extended to provide clients and facility managers with real-time management of data on the current conditions of the property, and to facilitate the analysis of alternative materials and systems, including life expectancy and cost analyses of various building products.

The application of conventional BIM systems and cloud-based BIM for planning the demolition and deconstruction of existing buildings (e.g. demolition simulation) (e.g. Cheng and Ma, 2013) is still limited. Cloud-BIM research in this area is still novel (Volk et al., 2014). Cloud-BIM technology should consider deconstruction and recycling functionalities (e.g. data on the demolition and recycling date of buildings, waste management and evaluation of material properties for recycling/reuse/landfill) for the end-of-life of buildings. Cloud-BIM should be expanded to provide cost analysis, such as comparison of the cost of retrofitting or demolishing a building to facilitate decision making by owners and clients.

While it is widely recognised that BIM-based technology is useful for helping project stakeholders to capture complete design and project information, it is also increasingly documented that BIM can make the best use of the available design data for sustainable design and sustainability rating analyses (e.g. Wong et al., 2013; Wong and Lau, 2013; Wong and Kuan, 2014; Wong et al., 2014a&b). Energy modelling work, however, is still considered a time-consuming and costly exercise (Yoders, 2014). Recently, a cloud-based BIM tool was developed to provide real-time building energy performance analysis (i.e Autodesk Formlt). The tool involves a Web- and mobile-based application (i.e. iPad/smart phone app) that enables users to gather instantaneous energy performance feedback on their design decisions and plans, such as the building orientation, thermal performance and massing. Another new cloud-BIM model involves a real-time cloud-based collaborative platform, which allows the architect and design consultants to work simultaneously on the data and model, and to import the results into BIM software such as Revit and Navisworks from virtually any mobile device. For building sustainability analysis, further research efforts are needed to investigate the pattern of business-process modelling, such as the information flow and information exchange requirements of various team members, for projects that aim to achieve sustainable building rating system certification via cloud-BIM technology (Wu and Issa, 2012). The issue of interoperability, model validation and assessment of the cloud-BIM model will need to be tackled in future studies (Wu and Issa, 2012).

Following the integration of cloud-based technology, BIM allows the remote exchange of data over a wireless network such as the Internet (Ijeh, 2012). However, the data management of a construction project becomes an issue that requires attention with the growing trend of cloud-BIM integration. While more data can be moved and shared amongst the project team via the Web, this type of cloud-based collaboration will require more powerful Web-based operating systems, file-sharing platforms and hardware controllers to support the consolidation and archiving of and increased access to project data (i.e. 'big data') (Yoders, 2014). In addition, the collaborative exchange model of cloud computing triggers security challenges, including the issues of responsibility, liability and model ownership arising from the system (Mahamadu et al., 2013). According to the latest report by McGraw Hill Construction on global BIM adoption (2014), contractors in many countries have expressed moderate (e.g. Germany, Japan, Brazil, Australia and New Zealand, France, Canada) to high (e.g. Korea, US and UK) levels of concern over the security of cloud technology. Contractual issues, including uncertainty over the ownership of shared data and the inadequacy of contractual relationships, are currently considered to be the main barrier to the adoption and integration of BIM and cloud computing (Redmond et al, 2012). Uncertainty over the assurance mechanisms and poor classification of the capability and capacity of cloud providers poses a challenge to the development of secure technology for cloud-BIM integration (Pearson and Benameur, 2010; and Sengupta et al., 2011). Inadequate information partitioning and protective mechanisms and the lack of a clear relationship management approach imposes risks for those adopting cloud computing. Mahamadu et al. (2013) pointed out that further research is needed to deal with the data security, ownership and stability issues to ensure secure collaboration using cloud-BIM technologies. Logical project-based solutions should be set up in relation to four levels, namely, infrastructure and technical, information partitioning and protection, legal and contractual management and relationship management (Mahamadu et al., 2013). While some researchers (e.g. Zhang et al, 2014) have made efforts to improve the efficiency and quality of information extraction/delivery and to ensure the safety and legality of data sharing through cloud BIM during the building lifecycle, more research is needed to improve understanding of the responsibility, liability and model ownership of cloud-BIM technology, as BIM-related legal and organisational frameworks vary between countries (Volk et al., 2014).

As cloud-BIM is still considered a novel technology, more efforts through education, training and changes in industry culture are needed to improve the understanding and adoption of this promising technology. While it is recognised that cloud-based websites or apps help to improve the communication and collaboration between construction team members on and off site, and thus enhance their 'competitive advantages' in the industry, a major concern is the complexity and expenses associated with technological adoption. Willingness to collaborate and cultural differences are still considered major barriers to the implementation of BIM technology, while training time and costs are hindering the adoption of cloud and BIM technologies within the sector (RICS, 2013). Research has pointed out that the industry lacks qualified personnel and experts for BIM implementation in new buildings (Volk et al., 2014; Bryde et al., 2013, Becerik-Gerber et al., 2012). There is a need for industry leaders and professional institutes to develop CPD training and set up industry standards, and to incorporate cloud-BIM technology into professional and tertiary education.

Cloud computing technology will undoubtedly have a profound effect on the AEC industry. Therefore, this special issue of ITcon aims to bring together some recent state-of-the-art developments in theory and applications of cloud computing technology in the AEC sector. For example, Xu et al. (2014) proposed a new concept of city information modeling (CIM) with the goal of bringing great benefits to the urban construction and city management. The model aims to enhance information sharing and multi-service and multi-field collaboration, and to achieve digital city full range of horizontal and vertical management, improve the overall efficiency of urban management. Goulding et al. (2014) presented a novel approach to support non-collocated design teams using Game-Like VR environments blended to Social Sciences Theory (social rules) and Behavioural Science Theory (Decision Science/Communication Science). This study provides new understanding and insight into the causal drivers and influences associated with successful decision-making design in non-collocated design teams. Enhancing health and safety in the construction industry is a major concern. Dawood (2014) developed an approach to enable a sandbox style serious game through the encapsulation of 4D (3D + time) concept in the game design with the hypothesis that this approach would influence the capability of trainee to spot safety hazards and the way they interact with the game. Liu et al. (2014) presented a framework to build a human behavior library through a BIM based cloud gaming environment, which grants players accessibility to games via thin clients. The proposed framework has the potential to solicit and collect human egress behavior data from a larger pool of human beings. Abrishami et al. (2014) proposed a conceptual framework for 'virtual generative design workspace' using BIM as the central conduit. It is posited that in order to address the entire requirements for BIM Level 3 (Cloud), a fully integrated system that supports all members of professional and construction team including AEC designers is a vital necessity. This study provided an example for digital integrating of all stages of AEC projects and implementing BIM Level 3 (Cloud). Hou et al. (2014b) developed a concept framework which aims to improve the productivity in the LNG construction industry. The approach is based on a novel context-aware mobile computing framework that integrates innovate concepts and technologies including but not limited to Information Communication Technology (ICT), Building Information Modeling (BIM), advanced visualization, Radio Frequency Identification (RFID) and laser scanning. Finally, Yung et al. (2014) constructed a BIM-enabled MEP coordination process based on IDEF0 language, which is particularly suitable for construction industry in China. The paper provides clear explanations about the inputs, controls, mechanisms and outputs of each sub-process in the BIM-enabled design process so that practitioners can easily adopt the model in real projects.

5. CONCLUSION

In recent years, the number of scholarly works on the application of cloud-BIM with the aim of promoting and transferring the technology to the industry has increased. However, such implementation is still in the initial stage, with limited adoption among the industry heavily focused on the design and construction phases. Despite the rapid growth of cloud computing technology in the IT field, only around 30 publications to date have presented state-of-the-art studies and applications of cloud-based BIM. Our literature review findings suggest that the major challenges facing the industry's adoption of cloud-BIM are i) a lack of clarity over who has the responsibility, liability and ownership of cloud-BIM models, ii) a shortage of expertise and technicians who can create, update and maintain information in the BIM cloud, and iii) the need for professional education and training on the new technology. The organisational and legal issues are considered to be the major hindrances to cloud-BIM implementation. Future research should further explore the potential of cloud-BIM in building operation/maintenance and facility management. The application of cloud-BIM for demolition/deconstruction planning is also an under-explored area of research.

6. REFERENCES

Abrishami S., Goulding J.S., Rahimian F.P., and Ganah A. (2014). Integration of BIM and generative design to exploit AEC conceptual design innovation, *Journal of Information Technology in Construction,* Special Issue BIM Cloud-Based Technology in the AEC Sector: Present Status and Future Trends, Vol. 19, 350-359, http://www.itcon.org/2014/21

Anumba C. & Wang X. (eds.) (2012a). *Mobile and Pervasive Computing in Construction,* Wiley–Blackwell Publisher.

Anumba C. and Wang X. (2012b). Mobile and Pervasive Computing in Construction: an Introduction, in C. Anumba and X. Wang (eds.), Mobile and Pervasive Computing in Construction, 1-10.

Baldwin A., Li H., Huang T., Kong C.W., Guo H.L., Chan N. and Wong J. (2009). Supporting pre-tender construction planning with virtual prototyping, *Engineering, Construction and Architectural Management.* 1Vol. 16, No.2, 150-161.

Becerik-Gerber B., Jazizadeh F., Li N., and Calis, G. (2012). Application areas and data requirements for BIM-enabled facilities management. *Journal of Construction Engineering and Management*, Vol. 13, No.8, 431-242.

Bhardwaj S., Jain L., and Jain S. (2010). Cloud computing: A study of infrastructure as a service (IAAS). *International Journal of Engineering and Information Technology*, Vol.2, No.1, 60-63.

Bryde D., Broquetas M., and Volm J.M. (2013). The project benefits of Building Information Modeling (BIM). *International Journal of Project Management,* Vol. 31, 971-980.

Chen H. M., and Hou C.C. (2014). Asynchronous online collaboration in BIM generation using hybrid client-server and P2P network, *Automation in Construction,* Vol. 45, 72-85.

Cheng J.C.P. and Ma L.Y.H. (2013). A BIM-based system for demolition and renovation waste estimation and planning. *Waste Management,* Vol. 33, No.6, 1539-1551.

Chong H.Y., Wong J.S. and Wang X. (2014). An explanatory case study on cloud computing applications in the built environment. *Automation in Construction,* Vol. 44, 152-162.

Chuang T.H., Lee B.C. and Wu I.C. (2011). Applying cloud computing technology to BIM visualization and manipulation. *Proceedings of 28th International Symposium on Automation and Robotics in Construction*. 144-149.

Dawood N., Miller G., Patacas J. and Kassem M. (2014) Construction health and safety training: the utilisation of 4D enabled serious games, *Journal of Information Technology in Construction*, Special Issue BIM Cloud-Based Technology in the AEC Sector: Present Status and Future Trends, Vol. 19, 326-335, http://www.itcon.org/2014/19

Doukas C., Pliakas T. and Maglogiannis I. (2010) Mobile Healthcare Information Management unitizing Cloud Computing and Android OS, *Proceedings of Annual International Conference of the IEEE on Engineering in Medicine and Biology Society (EMBC)*, October 2010, 1037 - 1040.

Dunston P.S. and Wang X. (2005). Mixed Reality-based Visualization Interfaces for the AEC Industry, *Journal of Construction Engineering and Management,* ASCE, Vol. 131, No.12, 1301-1309.

Dunston P.S. and Wang X. (2011a). A Hierarchical Taxonomy of AEC Operations for Mixed Reality Applications, *Journal of Information Technology in Construction,* Vol. 16, 433-444.

Dunston P.S. and Wang X. (2011b). An Iterative Methodology for Mapping Mixed Reality Technologies to AEC Operations. Journal of Information Technology in Construction, Vol. 16, 509-528.

Ercan T. (2010). Effective use of cloud computing in educational institutions. *Procedia-Social and Behavioral Sciences*, Vol. 2, No. 2, 938-942.

Goulding J.S, Rahimian F.P., and Wang X. (2014). Virtual reality-based cloud BIM platform for integrated AEC projects, *Journal of Information Technology in Construction*, Special Issue BIM Cloud-Based Technology in the AEC Sector: Present Status and Future Trends, Vol. 19, 308-325, http://www.itcon.org/2014/18

Grilo A. and Jardim-Goncalves R. (2011). Challenging electronic procurement in the AEC sector: A BIM-based integrated perspective. *Automation in Construction,* Vol.20, No.2, 107-114.

Hou L., Wang Y., Wang X., Maynard N., Cameron I., Zhang S. and Jiao, Y. (2014a). Combining

Photogrammetry and Augmented Reality towards an Integrated Facility Management System for the Oil Industry. *Proceedings of the IEEE,* Vol.102, No.2, 204-220.

Hou L., Wang X., Wang J. and Truijens M. (2014b). Integration framework of advanced technologies for productivity improvement for LNG mega-projects, *Journal of Information Technology in Construction*, Special Issue BIM Cloud-Based Technology in the AEC Sector: Present Status and Future Trends, Vol. 19, 360-382, http://www.itcon.org/2014/22

Ijeh I. (2012). *BIM Special Report: The Clouds Roll In.* http://www.building.co.uk/bim-special-report-the-clouds-roll-in/5047423.article, accessed on 11 June 2014

Jardim-Goncalves R., and Grilo A. (2010). SOA4BIM: Putting the building and construction industry in the Single European Information Space. *Automation in Construction,* Vol.19, No.4, 338-397.

Jiao Y., Zhang S., Li Y., Wang Y. and Yang B. (2013). Towards cloud augmented reality for construction application by BIM and SNS integration, *Automation in Construction*, Vol.33, 37–47.

Juan D. and Zheng Q. (2014). Cloud and open BIM-based building and information interoperability research. *Journal of Service Science and Management,* Vol.7, 47-56.

Kang L.S. et al. (2008). Development of major functions of visualization system for construction schedule data in plant project, *Korea Journal of Construction Engineering and Management,* Vol.9, No.1, 66-76.

Kim B-K. (2012). A study on the developing method of the BIM software based on cloud computing environment. *Proceedings of the World Academy of Science, Engineering and Technology,* Vol.6, 1487-1491.

Khmelevsky Y. and Voytenko V. (2010). Cloud computing infrastructure prototype for university education and research. *Proceedings of the 15th Western Canadian Conference on Computing Education,* Article 8.

Kumar B., Cheng J.C.P. and McGibbney L. (2010). Cloud computing and its implications for construction IT. *Computing in Civil and Building Engineering, Proceedings of the International Conference,* W. Tizani (Editor), 30 June-2 July, Nottingham, UK, Nottingham University Press, Paper 158 (p. 315).

Li M., Yu S., Zheng Y., Ren K. and Lou W. (2013). Scalable and secure sharing of personal health records in cloud computing using attribute-based encryption. Parallel and Distributed Systems, *IEEE Transactions*, Vol.24, No.1, 131-143.

Li H, Huang T., Kong C.W., Guo H.L., Baldwin A., Chan N. and Wong, J. (2008), Integrating design and construction through virtual prototyping, *Automation in Construction,* Vol. 17, No.8, 915-922.

Liu R., Du J. and Issa R.R.A. (2014). Cloud-based deep immersive game for human egress data collection: a framework, *Journal of Information Technology in Construction*, Special Issue BIM Cloud-Based Technology in the AEC Sector: Present Status and Future Trends, Vol. 19, 336-349, http://www.itcon.org/2014/20

Lohr S. (2007). *Google and I.B.M. join in "Cloud Computing" research.* The New York Times, Retrieved from http://www.nytimes.com/2007/10/08/technology/08cloud.html

Mahamadu A-M., Mahdjoubi L. and Booth C. (2013). Challenges to BIM-cloud integration: Implication of security issues on secure collaboration. *Proceedings of the 5th IEEE International Conference on Cloud Computing Technology and Science,* 209-214.

McGraw Hill Construction. (2014). *SmartMarket Report: The business value of BIM for construction in major global markets: How contractors around the world are driving innovation with building information modelling*. McGraw Hill Construction.

Mell P., and Grance T. (2011). *The NIST definition of cloud computing*. National Institute of Standards and Technology, Gaithersburg, MD, Special Publication 800-145.

Meza S., Turk Z. and Dolenc M. (2014). Component based engineering of a mobile BIM-based augmented reality system. *Automation in Construction*, Vol.42, 1-12.

Park C., Lee D., Kwon O. and Wang X. (2013). A Framework for Proactive Construction Defect Management using BIM, Augmented Reality and Ontology-based Data Collection Template. *Automation in Construction,* Vol.33, 61-71.

Pearson S., and Benameur A. (2010). Privacy, security and trust issues arising from cloud computing. *Proceedings of the 2nd IEEE International Conference on Cloud Computing Technology and Science.* Indianapolis, IN, 693-702.

Porwal A., and Hewage K.N. (2013). Building Information Modeling (BIM) partnering framework for public construction projects. *Automation in Construction,* Vol.31, 204-214.

Razak S.F.A. (2009). Cloud computing in Malaysia universities. *Proceedings of the 2009 Conference on Innovative Technologies in Intelligent Systems and Industrial Applications (CITISIA 2009)*, Monash University, Sunway Campus, Malaysia, 25-26 July 2009, 101-106.

Redmond A., Hore A., Alshawi A. and West R. (2012). Exploring how information exchanges can be enhanced through Cloud BIM. *Automation in Construction,* Vol.24, 175-183.

Rolim C.O., Koch F.L., Westphall C.B., Werner J., Fracalossi A. and Salvador G.S. (2010). A cloud computing solution for patient's data collection in health care institutions. *Proceedings of the eHealth, Telemedicine, and Social Medicine, 2010. ETELEMED'10. Second International Conference*, IEEE, 95-99.

Royal Institute of Chartered Surveyors (RICS) (2013). Publish electronically*,* RICS BIM survey results.

Sengupta S., Kaulgud V. and Sharma V.S. (2011). Cloud computing security - trends and research directions. *Proceedings of the 7th IEEE 2011 World Congress on Services.* Washington, DC, 4-9 July 2011, 542-531.

Starkov I. (2014). BIM for facility management, *BIM Journal,* http://www.bimjournal.com/2014/02/bim-for-facility-management/, assessed on 12 August 2014

Stein L.D. (2010). The case for cloud computing in genome informatics. *Genome Biol*, Vol.11, No.5, 207.

Tao J., Marten H., Kramer D. and Karl W. (2011). An intuitive framework for accessing computing clouds. *Procedia Computer Scienc*e, Vol.4, 2049-2057.

Vaquero L.M., Rodero-Merino L., Caceres J., and Lindner M. (2008). A break in the clouds: towards a cloud definition. *ACM SIGCOMM Computer Communication Review*, Vol.39, No.1, 50-55.

Volk R., Stengel J. and Schultmann F. (2014). Building Information Models (BIM) for existing buildings – literature review and future needs, *Automation in Construction*, Vol.38, 109-127.

Vouk M. (2008). Cloud computing - Issues, research and implementations. *Journal of Computing and Information Technology,* Vol.16, No.4, 235-246.

Wang X. and Dunston P.S. (2011). A User-Centered Taxonomy for Specifying Mixed Reality Systems for AEC. *Journal of Information Technology in Construction,* Vol.16, 493-508.

Wang X. and Dunston P.S. (2012). A Framework for Designing Mobile Virtual Training Systems through Virtual Modeling Technology, in C. Anumba and X. Wang (eds.), *Mobile and Pervasive Computing in Construction*, 37-53.

Wang X., Truijens M., Hou L. and Wang, Y. (2013). Application of Collaborative Mobile System in AR-based Visualization, Data Storage and Manipulation: A Case Study of LNG Project, *Lecture Notes in Computer Science*. Springer. Vol. 8091, 221-226.

Wang X., Truijens M., Hou L., Wang Y., Lavender M. and Zhou, Y. (2014). Integrating Augmented Reality with Building Information Modelling: Onsite Information Sharing and Communication for Liquefied Natural Gas Industry, *Automation in Construction,* Vol. 40, 96-105.

Wong J.K.W., Li H., Wang H., Huang T., Luo E. and Li V. (2013). Toward low-carbon construction processes: the visualisation of predicted emission via virtual prototyping technology, *Automation in Construction,* Vol. 33, 72-78.

Wong J.K.W. and Lau L.S-K. (2013). From the 'urban heat island' to the 'green island'? A preliminary investigation into the potential of retrofitting green roofs in Mongkok district of Hong Kong, *Habitat International,* Vol. 39, 25-35.

Wong J.K.W. and Kuan K-L. (2014). Implementing 'BEAM Plus' for BIM-based Sustainability Analysis, *Automation in Construction,* Vol.44, 163–175.

Wong J.K.W., Li H., Chan G., Wang H., Huang T., Luo E. and Vera Li (2014a). Publish electronically*,* Virutal prototyping for construction site CO2 emissions and hazard detection, *International Journal of Advanced Robotic Systems*, Vol.11, 1-9.

Wong J.K.W., Li H., Chan G., Wang H., Huang T. and Luo E. (2014b). An integrated 5D tool for quantification of construction process emissions and accident identification, *Proceedings of the 31st International Symposium on Automation and Robotics in Construction and Mining (ISARC2014)*, July 9-11, Sydney, Australia.

Wu W. and Issa R.R.A. (2012). Leveraging cloud-BIM for LEED automation, *Journal of Information Technology in Construction,* Vol.17, 367-384.

Xu, X., Ding, L., Luo, H. and Ma, L (2014). From Building Information Modeling to City Information Modeling, *Journal of Information Technology in Construction*, Special Issue BIM Cloud-Based Technology in the AEC Sector: Present Status and Future Trends, Vol. 19, No. 17, 292-307, http://www.itcon.org/2014/17

Yoders J. (2014). *5 Tech Trends Transforming BIM/VDC* http://www.bdcnetwork.com/5-tech-trends-transforming-bimvdc, accessed on 11 June 2014

Yung P., Wang J., Wang X. and Jin M. (2014). A BIM-enabled MEP coordination process for use in China, *Journal of Information Technology in Construction*, Special Issue BIM Cloud-Based Technology in the AEC Sector: Present Status and Future Trends, Vol. 19, No. 23, 383-398, http://www.itcon.org/2014/23

Zhang Q., Cheng L. and Boutaba R. (2010). Cloud computing: state-of-the-art and research challenges. *Journal of Internet Services and Applications*, Vol.1, No.1, 7-18.

Zhang J., Liu Q., Yu F., Hu Z. and Zhao W. (2014). A Framework of Cloud-Computing-Based BIM Service for Building Lifecycle, *Computing in Civil and Building Engineering*, 1514-1521.

Zhang S., Yan H. and Chen, X. (2012). Research on key technologies of cloud computing, *Physics Procedia*, Vol.33, 1791-1797.