Application of Building Information Modeling (BIM) and Information Technology (IT) for Project Collaboration

Lijun, Shen[1], and David, K.H. Chua[2]

Abstract

The Architecture, Engineering and Construction (AEC) industry is characterized by fragmentation, in the forms of interface fragmentation among temporary processes vertically throughout project life cycle and collaboration fragmentation among different roles horizontally interacting with each other. Building Information Modeling (BIM) is an enabling technology that helps reduce such fragmentation through the employment of a single 3-dimentional geometry model and a full range of integrated value-adding services tailored for various phases of project development. However, the present implementation of BIM still has many barriers in the technical, financial and managerial aspects that need to be overcome. This paper presents three emerging Internet-based technologies, namely, semantic search, cloud computing and mobile computing, and discusses their benefits and potentials in promoting BIM implementation and adoption to a much wider user base. A framework of an integrated project management portal based on BIM and the above Internet technologies is proposed, aiming at lowering the entry barrier of BIM adoption and extending the capability of present project functions using BIM services. Five use cases involving different processes and project roles are demonstrated.

Keywords: Building Information Modeling (BIM), Semantic Search, Cloud Computing, Mobile Computing, Project Collaboration, Internet

Introduction

The Architecture, Engineering and Construction (AEC) industry is characterized by fragmentation, in the forms of interface fragmentation between temporary processes vertically throughout project life cycle and collaboration fragmentation between different roles horizontally interacting with each other. Fragmentation considerably reduces productivity when multiple processes and participants work together due to the problems of data incompatibility and inefficient communication. One example is the significant amount of time wasted in re-generating geometry data based on 2-dimentional drawings by various specialists for design and engineering analyses. Another example is fragmented information updating and poor change management, which frequently disrupt processes and consequently delay the project.

Building Information Modeling (BIM) is an enabling technology that helps reduce project fragmentation through the employment of a single 3-dimentional geometry model and a full range of integrated value-adding services tailored for various phases of project development. BIM provides a shared digital representation and an interoperable process for professionals to collaboratively design, build and operate a facility. Comparing with 2D drafting and 3D visualization/rendering technologies, BIM features an object-oriented CAD

1 Lecturer, Dept. of Civil Engineering, National University of Singapore, 10 Kent Ridge Crescent, Singapore 119260, (65)65162226, ceesl@nus.edu.sg

2 Associate Professor, Dept. of Civil Engineering., National University of Singapore, 10 Kent Ridge Crescent, Singapore 119260, (65) 65162195, FAX (65) 67791635, ceedavid@nus.edu.sg

and parametric 3D geometry model shared in a neutral and open specification called Industry Foundation Class (IFC) data model, which is currently in the process of becoming an official international standard. BIM offers a holistic approach to enhance project cooperation and collaboration and achieve better interoperability among multi-disciplinary project processes and participants.

With the maturing of BIM tools and platforms, an increasing number of BIM services are being adopted in various project functions, including building performance analysis (e.g. thermal, energy, lighting and acoustic), structural engineering, quantity estimation, cost analysis, constructability analysis, 4D scheduling and facility management. Application domains also spread extensively, including bridges, buildings, public facilities, communication networks, geotechnical and geoenvironmental engineering, mining and metals, power generation, process manufacturing, rail and transit, roads, utility transmission and distribution networks, water and wastewater treatment plants, etc (Bentley, 2010). BIMManager (2010) reported that 50% of the users responding to a survey voted that they worked over 60% of their projects in BIM in 2010, up from just 30% in 2009. Countries such as the Unites States, Finland and Norway have made BIM mandatory for public sector building projects. In Singapore, mandatory regulatory submissions using BIM would be progressively introduced for architectural submission (by 2013), structural and M&E submissions (by 2014) and eventually for plan submissions of all projects with more than 5000 m^2 by 2015 (BCA, 2011).

However, there are still many challenges in adopting BIM in the traditional work processes, especially for those smaller players in the AEC industry who have limited resources and are reluctant to embrace new technology. Some obstacles include steep learning curve, high upfront cost in hardware and software, lack of suitable applications for certain users, and the concern about overall cost to implement and maintain BIM compliance. In contrast, many Internet technologies such as email, search, file sharing and mobile device based applications have been widely adopted by even the non-technical people. In this paper, we present three emerging Internet technologies, namely, semantic search, cloud computing and mobile computing, and explore their potentials in promoting BIM implementation and adoption to a much wider user base. A framework of an integrated project management portal based on BIM and the above Internet technologies is proposed, aiming at lowering the entry barrier of BIM adoption and extending the capability of present project functions using BIM services. Five use cases involving different processes and project roles are demonstrated.

Building Information Modeling

Lee et al (2006) described BIM as *the ‘‘process’’ of generating and managing building information in an interoperable and reusable way*; and *a BIM system is a system or a set of* systems *that ‘‘enables’’ users to integrate and reuse building information and domain knowledge through the lifecycle of a building*. Typically a BIM system uses a 3-dimentional object-oriented CAD model for creating and managing dynamic real-time virtual building elements in 3D objects. 3D objects have several advantages over 2D symbols as they can represent building geometry, spatial relationships, geographic information, and functional relationships between building elements. 3D objects also can be displayed in multiple views, assigned with non-graphical attributes, and used for modeling and analyzing domain specific problems. It is the 3D object that makes a BIM platform more “intelligent” than a 2D drafting CAD.

Another key feature of modern BIM systems is the parametric design of elements, which define objects as parameters with relationships to other objects. Whenever a parametric element is modified, the entire BIM model can be automatically updated based on the embedded rules. This could dramatically improve productivity and eliminate many potential problems related to drawing updates.

Furthermore, BIM enables a transition from 3D CAD visualization/rendering to interoperable nD CAD modeling and analysis (Lee et al, 2005), which stand for the practice of integrating multi-level professional services on top of a single 3D object CAD model. One big advantage is the elimination of recreating geometry data by individual specialists. Another advantage is data interoperability though the implementation of IFC data format, which allows using different BIM tools from different vendors to analyze a CAD model. Interoperability at data level could effectively reduce fragmentation in interface management and collaboration management in the AEC work flow.

There are several limitations in the current practice of BIM. First, the interoperability of BIM model is largely limited to the geometry data in IFC specification. For non-geometry data and various input/output data associated with nD analyses, there is no standard format. This makes it difficult to search and share data between different BIM functional processes. Second, many companies are reluctant to adopt BIM because of high upfront investment in hardware, software and training. There is also concern about the total cost for migrating to BIM platform. Third, most present BIM users are architects and engineers, while many other players such as construction workers on site and suppliers have little involvement. These groups of participants should and could contribute to the information flow if equipped with suitable tools, such as BIM enabled mobile devices.

Considering the above limitations, we examine three Internet technologies, namely, semantic search, cloud computing and mobile computing, and identify their values in enhancing the present BIM practice as shown below.

Semantic Search

Semantic search differs from keyword-based search in that it analyzes the contextual meaning of terms, creates concepts and relationships out of data and metadata, and provides rich search results from various sources in the search space. With natural language processing and ontology representation, semantic search engine can, to a certain degree, understand the meaning of data, infer implicit facts, and conduct automatic reasoning process. Semantic search also enables machine-based learning process through ontology mapping, which can efficiently expand knowledge base in a heterogeneous environment.

Semantic search technology can fundamentally increase the value of BIM. First, a BIM model represents building elements in 3D objects with well-defined geometry and non-geometry attributes. Semantic search engine can make use of this structured model to construct a knowledge base and share it with other knowledge bases. Second, semantic search can substantially improve data and file management using ontology mapping to mash up data based on concepts and relationships. Third, semantic search allows for complex search queries across several data sources. For example, it is possible to search "the schedule of all room units in zone 1 between 3^{rd} to 4^{th} story where contractor A and supplier B are involved and a special equipment C is required". This query requires an integration of geometry data, organizational data and project schedule. Although manual search and analysis is an option, semantic search makes this type of tasks much more efficient. Fourth, computer agents with semantic search capability can be deployed to automatically search, integrate, conduct reasoning and make decision to delegate human roles in many tasks.

Cloud Computing

According to Marston et al (2011), cloud computing is an information technology service model where computing services (both hardware and software) are delivered on-demand to customers over a network in a self-service fashion, independent of device and location. The resources required to provide the requisite quality of service levels are shared, dynamically scalable, rapidly provisioned, virtualized and released with minimal service provider interaction. Users pay for the service as an operating expense without incurring any significant initial capital expenditure, with the cloud services employing a metering system that divides the computing resource in appropriate blocks. Cloud computing offers several key advantages, such as (1) lower entry cost for smaller firms to use compute-intensive resources available only to the largest corporations; (2) immediate access to hardware resources with no upfront capital investment; (3) high scalability dynamically adjusted according to user demand; (4) cost-effective pay-per-use utility computing model; (5) widely accessible platform for inventing new business model based on cloud computing, virtualization, storage and sharing.

Application of cloud computing in BIM is still preliminary at the present stage; nevertheless its huge potential has been recognized. First, software vendors can create new tools and systems deployed on cloud to attract a much wider user base. Second, many project functions can be re-designed to take advantage of cloud infrastructure. Meanwhile, new project functions can be invented. Third, usage of cloud-based project services can be scaled up and down smoothly without the need for upfront cost and the total cost can be reduced. Fourth, it helps break the barriers between different processes and reduce project fragmentation by implementing integrated work flow and project-wide collaboration using cloud services.

However, concerns and limitations do exist towards cloud computing, such as data ownership, security, speed of network, and service support. Some of these issues can be solved by deploying private cloud (or enterprise cloud) for mission critical data and applications, duplicating cloud servers for long geographical distance projects, and providing regular training to staff. On the other hand, research and development in cloud computing need to be carried out so that the best practices can be delivered to the AEC professionals in the near future.

Mobile Computing

Mobile computing here refers to the execution of project functions with support of mobile devices (laptop, phone and tablet), mobile software applications and mobile communication protocols. To a greater extent, mobile computing also involves sensors (collecting data), servers (processing data), and software agents (delegating human in certain routine tasks). It has been increasingly acknowledged that mobile computing plays a crucial role in today's project management and it will be a key component in the BIM solution. First, up-to-date information is important for quality decision making. Mobile computing is a very efficient way to collect information due to the wide adoption of mobile devices such as mobile phones. Second, it allows the users to access BIM digital CAD model anytime anywhere and make changes instantly available for others. Third, it strengthens the position of BIM as a full digital approach to AEC project management by eliminating many intermediate data input and conversion processes. Fourth, it is an intuitive and efficient way to connect with other project participants and achieve collaborative project management on the go. Fifth, it can speed up data collection, decision making, and communication loop with the deployment of sensors and software agents to handle many routine tasks.

Based on the above discussion, we propose a framework of an integrated project management portal that exploits the power of semantic search, cloud computing and mobile computing to achieve better search, better deployment, and better communication for BIM implementation.

Framework of Enhanced BIM Applications

Figure 1 shows a framework of BIM solutions implementing semantic search, cloud computing and mobile computing. Many use cases can be identified from this framework.

On the top are project participants and project functions. As BIM is a total project management paradigm throughout the life cycle of a facility, most project functions can benefit from this process. 3D conceptual CAD model can be created as early as feasibility study stage. More details are added during the phases of architectural design, building performance analysis and structural analysis, etc. The 3D CAD model can be submitted to government agency for code checking. After the project is approved, purchase orders can be made. Thereafter, project manager works on planning, scheduling and resource allocation; contractor conducts constructability analysis; contract manager and safety manager, for example, carry out their professional services. Eventually the project is complete and facility manager takes over for business operation. At each phase of project development, a single 3D CAD model is maintained while additional analyses can be generated for special purposes.

In the second layer, a wide range of devices are listed catered for different types of users. Workstation is suitable for power users who are demanding for computational resources to run full-fledged software such as Revit and Bentley's RAM structure system. A typical workstation includes multi-core CPU and GPU graphical accelerator. However, if computational intensive software can be migrated to cloud services, the need for powerful workstation would be reduced. As a matter of fact, a user can create multiple virtual instances performing several parallel analyses to be finished in much shorter time taking advantage of cloud scalability. Notebook/laptop is becoming standard equipment for many BIM adopters due to its mobility. With cloud computing, the advantage of notebook is even more obvious as most time-consuming tasks are handled with cloud services, while notebook is used for visualization and updating information. Tablets and mobile phones are newcomers attributed to the boom of mobile applications in last couple of years. Apple's iPhone/iPad and Android based phone/pad become essential business tools replacing the role of notebook/netbook in many use cases. We will certainly see more mobile apps for BIM in the future. Sensors are another type of devices that greatly benefit data collection. With the advancement of wireless technology, sensors can be deployed flexibly to facilitate BIM management.

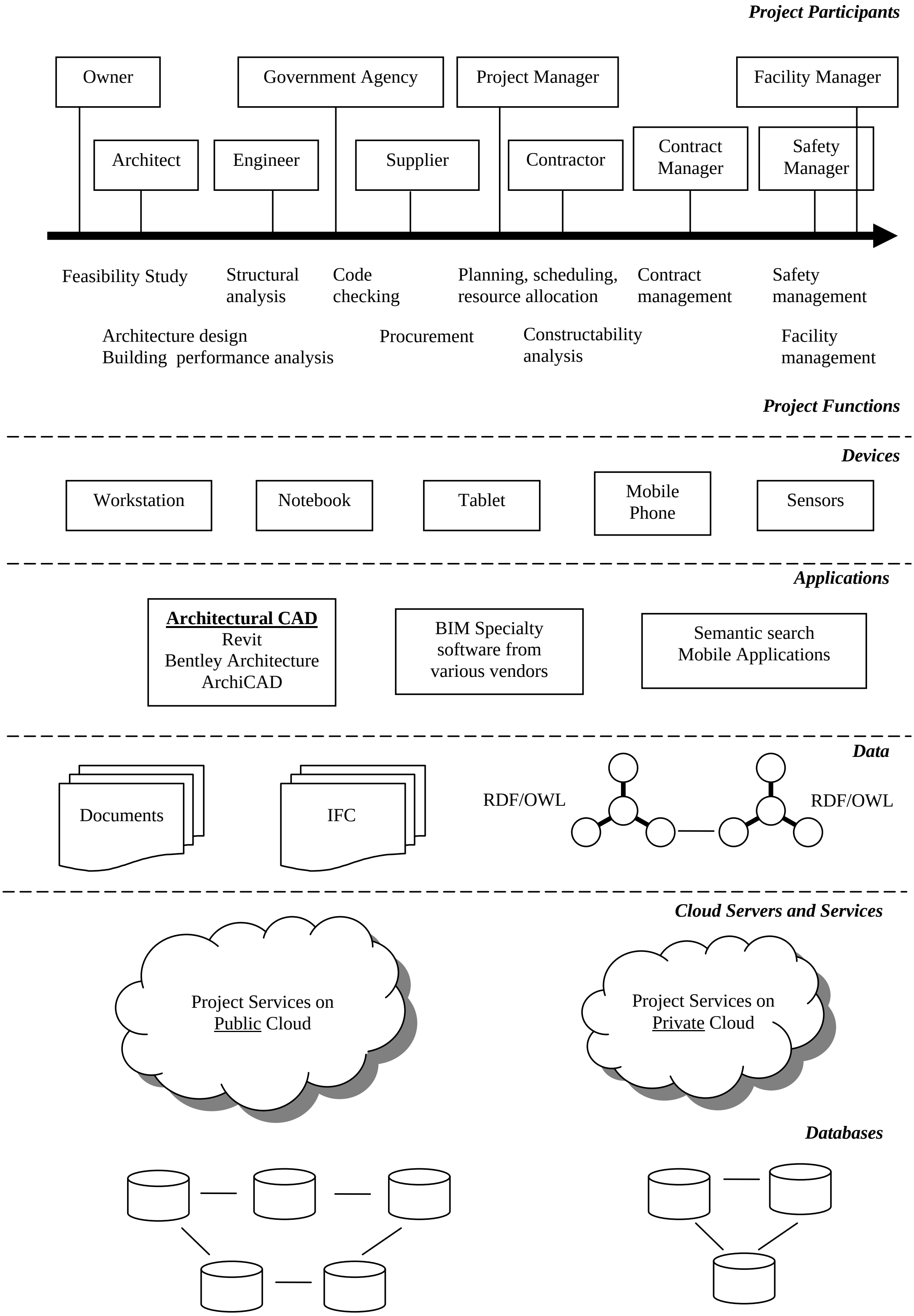

Figure 1: A Framework of BIM Solutions Implementing Semantic Search, Cloud Computing and Mobile Computing

The third layer includes applications deployed in the devices. Beside CAD and other supporting BIM tools, two additional applications are added here, e.g. semantic search and mobile application. Semantic search provides users advanced search function based on concepts and relationships of terms. Search results can be integrated from various sources, including complex data such as drawings and schedules. Mobile applications are tailored for light-weight use of BIM model and feedback of information. Both of these applications are under rapid research and development.

The fourth layer includes data consumed by project applications. RDF/OWL is an addition to the IFC-based CAD model. RDF represents Resource Description Framework, which is an international standard for modeling metadata. OWL is Web Ontology Language, which is a higher level semantic language over RDF. Both of the standards provide interoperability of knowledge representation and management in the scope of web application. With RDF/OWL, BIM adopters can search and exchange information with extended interoperability on top of IFC data format. This also provides a means for integrating AEC applications with other web applications.

The fifth layer includes cloud servers, services and databases. The cloud services are delivered in three levels: infrastructure, platform and software. At infrastructure level, users rent infrastructure from cloud service providers to develop and deploy their own applications. At platform level, users develop and deploy their software making use of available platforms provided by cloud service providers. At the software level, users simply use software offered by the cloud service providers to do something. All these three level of services are useful for different types of BIM applications. Cloud services can be deployed on public, private or mixed cloud topology. Public cloud is provided by a vendor in the open market. Private cloud, or enterprise cloud, is configured within a company's IT infrastructure for the concern of security and performance. Sometimes a mixed cloud architecture provides more flexibility and higher cost advantage.

Use Cases

At here we discuss five use cases of project functions that can benefit from the integration of BIM with semantic search, cloud computing and/or mobile computing.

Code checking

Code checking is a regulatory service typically provided by government agency to verify whether a BIM design is compliant with regulatory codes. In Singapore, the BCA CORENET e-Plan Check system initiated in 2000 is one of such pioneer expert systems built on client-server architecture. The work flow begins with digital drawing submission in IFC-format 3D CAD model. On the server side, each code is translated into an algorithm to be executed against the BIM model. This is a computational intensive process. The client-server architecture does not scale well when request for service fluctuates. A cloud computing architecture can be adopted leveraging the scalability of CPU and storage to better handle peak demand and enable parallel processing as well as avoiding upfront capital investment using public cloud. If the service must be deployed on a private cloud, the resources still can be shared with other applications to maximize the value of investment.

Building performance simulation, structural analysis and constructability analysis

Building performance simulation is a value-adding service which analyzes the impact of built environment and employs good design practice in energy, thermal, acoustic, lighting and airflow to improve indoor quality and productivity. Structural analysis is a service determining the effects of loads on physical structures and their components.

Constructability analysis is a process to determine if a construction project can be achieved by utilizing common construction practices. These services require data input (e.g. material, prefabricated units, work methodology and space) from diverse sources in non-standard formats. They also generate application specific data that cannot be directly used by other BIM services. Semantic search technology provides a solution here by introducing a standard data format (RDF/OWL) to complement IFC with enhanced interoperability. This makes data sharing between BIM and non-BIM applications more effective. For example, it is possible to automatically select materials and conduct analysis when material catalogs are obtained in RDF/OWL format. Meanwhile, the analysis results can be shared with other BIM applications by providing metadata in RDF/OWL format for easier retrieval. On the other hand, simulation and engineering analysis are resource demanding tasks. This type of heavy-lifting applications can be migrated to the cloud so that even a user with light computing device can conveniently generate results within a reasonable time frame.

Contract management

The role of contract management is to ensure compliance with terms and conditions and document any changes or amendments during project execution. This requires a good understanding about the terms and conditions in contracts as well as an efficient search function to find information in documents. Traditional file search is based on keywords, which has several limitations to deal with large number of files/data. This is because when a result is found match the keywords, contract manager needs to manually check if it is relevant. It could be a time consuming process if many irrelevant results are found. In addition, keywords search does not handle synonym and misspelling. Semantic search is a promising technology which can be employed to enhance contract management. First, it is more efficient to deal with large number of files/data as semantic search can analyze semantics hence it reduces human intervention. Second, semantic search can take complex queries, analyze the concepts and relationships of search terms, and provide mashup data presenting integrated search results. This is a feature which cannot be achieved by keyword search. Third, semantic search is capable of handling structured data (e.g., database), non-structured data (e.g. text file), and even binary data if metadata if available. This extends the search capability to multimedia and proprietary data. Fourth, semantic search allows contract manager to build knowledge base and quickly expand knowledge base via connecting to other semantic knowledge base using ontology mapping.

Project Scheduling, Control, and Constraint Management

Scheduling and control are important project functions ensuring smooth project execution and good resource management. Constraint management is the key to remove bottlenecks from the schedule. During construction phase, many activities and participants are involved. Semantic search allows automating the process of conflict resolving by using ontology mapping to detect the source of problem and negotiate a solution to reduce delays. For example, if an activity cannot start on time due to the delay of material delivery, all impacted activities and resources can be located using semantic search and ontology mapping and a revised schedule can be generated after several rounds of negotiation between human and delegating software agents. Mobile applications play an essential role facilitating instant information feedback and speeding up decision making process.

Safety Management

With BIM and sensor technology, safety management can be improved. Construction site and the crew can be monitored in real time. Unsafe practice may be detected, which triggers alert to mobile application and document the event for rectifying and training purposes.

Conclusions

BIM provides a holistic approach to facilitate AEC project development with better cooperation and collaboration among diverse processes and participants. The current BIM practice can be enhanced with three Internet-based technologies: semantic search, cloud computing and mobile computing. Semantic search extends the interoperability of BIM services by employing another open standard (RDF/OWL) for data sharing/mapping, search and integration. Cloud computing facilitates the adoption of BIM with lower entry cost and better scalability. When more cloud-based BIM services are available in the future, this transformation is expected to be accelerated. Mobile computing provides an excellent infrastructure for even non-technical people to embrace new technology. It can be an essential component in the BIM work flow serving as an efficient channel for information feedback and easy access to BIM model anytime anywhere. Admittedly, these Internet technologies are still rapidly evolving and the current standards and practices are far from mature. However, we believe they can fundamentally increase the capability of BIM and consequently change the way of traditional AEC project development.

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