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Cloud and Open BIM-Based Building Information Interoperability Research*

Du Juan[1,2,3], Qin Zheng[1]

[1]School of Information Management and Engineering, Shanghai University of Finance and Economy, Shanghai, China
[2]SHU-UTS SILC Business School, Shanghai University, Shanghai, China
[3]SHU-SUCG Research Center for Building Industrialization, Shanghai, China
Email: ritadu@shu.edu.cn

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Abstract

The emergence of Open BIM effectively improves the interoperability of building information. Besides, cloud technology supports virtualization and QoA (Quality of Assurance) in the case of the distributed system and multi-user collaboration. Based on the cloud and the Open BIM, this paper puts forward the cloud services models and the cloud-based Open BIM building information interaction framework, and further illustrates the architecture of cloud deployment pattern and the information interaction process. Finally, the paper takes underground rail transit project as example and explains how to deploy and implement the tunnel construction management platform.

Keywords

Open BIM, Cloud, Interoperability, Tunnel Construction

1. Introduction

In the development process of the Architecture Engineering Construction (AEC) industry, as the lack of unified standard and integration mechanism to build information interoperability, the information exchange and sharing between different building application systems in the different phases of the building life are difficult. Besides, thus phenomenon formed the information islands and faults, hindered the application of information technology in the field of construction, so as to influence the production efficiency of construction industry [1]. With the appearance of BIM technology around building life cycle, it is realized that the building information integration and sharing between different parties and different stages. BIM provides the technical support to solve the low

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efficiency problem caused by the poor information transmission [2]. With the mature of cloud technology, it becomes more convenient to access remote data servers and applications based on web services. Thus the combination of the open data-exchange mechanism and distributed network architecture provides effective technology platform in AEC industry [3].

2. Literature Review

2.1. BIM and Open BIM

BIM is the full name of Building Information Modeling. On the basis of 3D digital technology, through a common standard, BIM integrates various construction project related information data models. BIM are digital construction representations with rich data, object oriented intelligent and parametric characteristics. BIM provide the coordinated information to all the parties involved in the project throughout the life cycle. BIM fulfill the following construction work such as the analysis, visualization, construction drawing, quantity statistics, etc, so as to help users increase efficiency, cut costs, and reduce environmental impact [4]. In the specific practice of BIM, the potential value of the information exchange around the building life cycle has not been fully realized. The storage and read of BIM information, the transformation and transition of BIM model are restricted by many factors, the most significant one of which is the realization of information interoperability, namely the exchange and sharing of project information between participants and different application systems. Because of the characteristics of the building information, such as huge quantity, complex types, wide resources and scattered storage, the efficiency and effectiveness of information communication and exchange between each subsystem and the various project participants is critical vital to the successful implementation of the project. Traditional way of information interaction mainly through API (Application Programming Interface), or by developing a special intermediate file formats, such as DXF, SAT, 3Ds, etc., to realize transformation and integration of sub-models. These two approaches in use cover a common problem, compatibility [5]. Mostly it can only solve the model transformation between individual software, and once function or version changes, conversion middleware also need to adjust and adapt.

In order to improve the interoperability, the Open BIM initiative, organized by building SMART and the major software vendors such as GRAPHISOFT, Tekla, is put forward [6]. Open BIM is the data management and model method not dependent on specific software or format. The current mainstream Open BIM use public product data IFC (Industry Foundation Classes) to realize information interaction. IFC is the BIM data standard released by the International collaborative work union (International Alliance for Interoperability, IAI). Based on the experience of the industry STEP standard, IFC is the construction data representation and interchange standard that computer can process [7]. The goal of IFC is to provide a neutral mechanism that independent on the specific system and suitable for describing product data throughout the building life cycle and can effectively support the data exchange between various application system and related construction data management.

The data model structure of IFC standard (IFC Schema) can be divided into four layers, including the domain layer, interactive layer, core layer and resource layer, each layer contains certain information description module, and each layer can only reference the same level and the information resource of lower level, and can't quote the upper level's resources. The resource layer of IFC standard is mainly used to describe the basic information of the model, and thus information is general information independent of the specific construction. The core layer defines the basic framework of the IFC data model, and organizes the information of the resource layer into structured data, such as the Product entity, Process entity and Control entity. The sharing layer defines multiple shared concepts and the objects, resolve the information interaction between different areas. The domain layer defines the specific concepts and information entities of a construction project. This article is based on the IFC's data model structure to complete information interoperability framework.

IFC provides the geometric information and non-geometric properties of the building components, as well as the connection between the components, covering all the data structure at various stages of building life cycle. Although IFC covers all the objects of building life cycle, in the process of practical application, IFC cannot completely solve the problem of building information interoperation. Because the IFC data model just gives the general data structure of building and does not give detailed description for specific building project. Therefore, based on use case to define information interaction requirements become another important aspect of the IFC development, namely the Information Delivery Manual (IDM) [8]. IDM module provides a set of basic building process, and through the analysis to use case, information handbook defines the key points in the process of information exchange, which contributes to building design and construction of information interaction. IDM will become the important foundation of sub-model extraction and conversion.

2.2. Cloud Service in AEC

As two pillars of BIM, IFC and IDM can only solve basic data storage and transformation, and the transfer of the models in the construction project between different stages also need the support of network environment in order to realize the multi-user access and collaborative interaction. The web-based open information model structure can effectively improve the efficiency and convenience of construction information interaction, and can realize the effective management and cross-platform flexibility. Cloud [9] contributes to exchanging information more effectively and efficiently throughout the building life cycle. The possible solution is the binding of heterogeneous applications through a central repository platform, such as in "Cloud" computing, which has created a way for different applications to openly interoperate and exchange information. Cloud computing is both the applications delivered as service over the internet and the hardware and system software in datacenters that provide those services.

Based on the literature, the research related to Open BIM most refers to construction scheduling [10], traditional building design [11] and solar PV simulation [12], where there has a gap to link Open BIM with cloud technology. Besides, the research to cloud in AEC field is also stay in an early stage, such as the construction data storage [13], cloud security [14] and key technologies [15]. Therefore, it is necessary to consolidate cloud computing with Open BIM and research the cloud deployment and architecture.

There are two categories of cloud-based construction information service provider. One is cloud providers who mainly offer the infrastructure and basic service of cloud. The other is cloud service providers who directly serve various classes of users in construction professional field to meet their particular requirements of the development, integration and release of specific service.

According to the characteristics of the construction industry, there are three types of cloud services deployment model:

1) Software as a Service (SaaS): Cloud service providers enable mainstream software packages available on the cloud platform, so users can choose to rent the software service and use the relevant software service conveniently and quickly, simply by a web-enabled device, such as ordinary computer and Tablet PC. Take Autodesk360 as a typical example. Autodesk360 is able to help users to optimized design, visualize, simulate and share data and processes at any time. For instance, users can view and edit engineering design data, or share and view various types of project files via the platform. Users can enjoy the software service without purchasing a great number of expensive hardware and software.

2) Platform as a Service (PaaS): There must be various types of applications different from cloud providers in different kinds of professional software used inside construction companies. The legacy software can also interact with other software through the cloud platform. Users can rent highly integrated application environment offered by cloud providers or cloud service providers in order to create, test and deploy their own application software as well as realize the interaction between the existing software and other software through the interface. Those kinds of service target application-centric users who can greatly reduce or even dispense with their purchase and maintenance costs of middleware products by the platform service.

3) Infrastructure as a Service (IaaS): Cloud providers with a certain power can provide their service to construction domain cloud service providers or construction companies with a certain scale. These users will put the operating system, middleware, and applications into the cloud of the virtual machine and the dynamic elastic cloud infrastructure and platform.

3. Cloud and Open BIM-Based Building Information Interoperability Framework

Cloud and Open BIM-based building information interoperability framework includes Infrastructure layer, data layer, model layer, interactive layer and application layer (Please see **Figure 1**). The framework has the similar layer division compared with the IFC standard, which indicates that the Open BIM is highly relying on the IFC standard.

1) Infrastructure Layer

This layer mainly contains all kinds of physical resources and virtual resources: private cloud, public cloud, hybrid cloud and community cloud. By using the virtual calculating technology, virtual storage technology, hardware devices virtual technology and condition monitoring, this layer realize the virtual dynamic matching

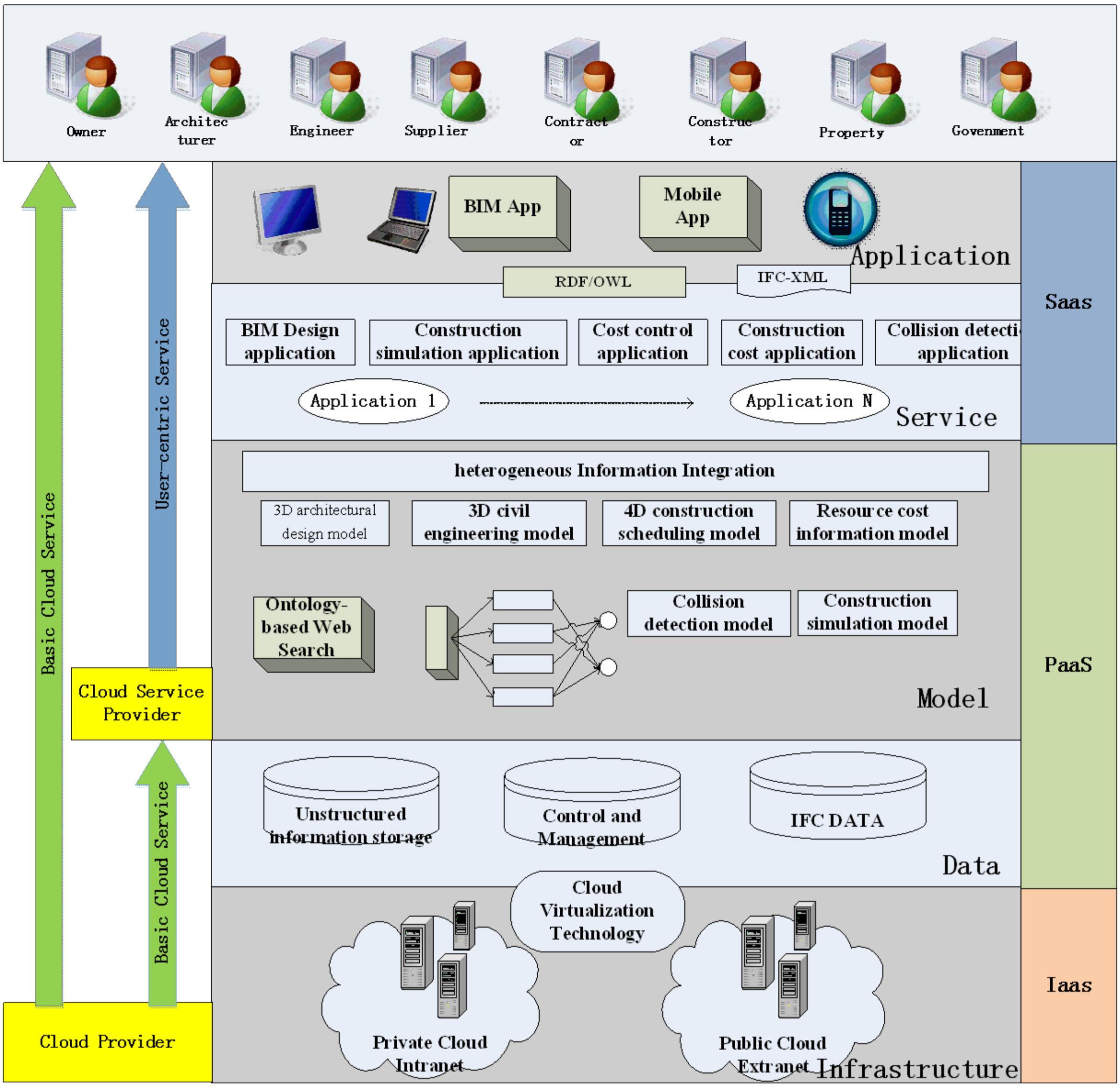

Figure 1. Cloud and Open BIM-based building information interoperability framework.

and provision. Infrastructure layer is mainly composed of cloud providers to provide high reliability, strong customizable, scale extensible service, namely the IaaS services.

2) Data Layer

This layer contains the project information in the whole life cycle of buildings. The information can be divided into three categories, namely the building information model based on the IFC, unstructured data and information (such as RFID data from sensor reading, manual input data, external data from GIS, or media data from audio and video) and process management control information. These data information is stored in a distributed network environment. Through virtualization technology, the huge amounts of data stored on the cloud platform, and will be invoked and processed according to user's demand.

3) Model Layer

This layer mainly includes the combination of the data model used by the specific business process. The building information and information service group are encapsulated based on Web service standards, through the use of semantic based retrieval functions and form business process modeling through the workflow engine. As all kinds of data in the data layer can be expressed by ontology, based on the semantic relations, retrieve result can be formed, such as the data processing model, 3D architectural design model, 3D civil engineering model, 4D construction schedule model and resource cost information model, collision detection model, etc. Using the Open BIM standard, Firstly, based on the specific business requirement, select or determine the business of IDM, then apply sub-model extraction technology from BIM database to extract the BIM model, then export to IFC files and provide the usage to related application system. Application system use the imported IFC files to realize the engineering information sharing, and then complete the relevant business processes, add new project information, then export the new information and original information to the IFC files. Finally, integrate the new IFC export file into BIM database.

Based on the data layer and model layer, the users deploy and configure their software running environment according the demand. The cloud service providers develop different application services, BIM program interface, BIM service or other auxiliary functions in the development and running environment, namely the PaaS services.

4) Service Layer

This layer mainly includes a variety of heterogeneous applications and software, such as BIM design, construction simulation, cost control, collision detection, etc. the interaction between Software and user client information, can be based on RDF/OWL language to describe. Using XML for data transformation, the user sends a service request and then waits for receiving the server information feedback, without having to download the complete IFC data files, greatly improving the response speed of information interaction. XML Schema due to its complexity, the non-professional users have to write many invalid file, and Web services can effectively solve these problems. Cloud contributes to exchanging information more effectively and efficiently throughout the building life cycle. This cloud BIM middleware will be used to create and modify new data by using SOA and plugins/open APIs.

5) Application Layer

This layer includes the functional project participants and the execution of projects. Based on cloud platform, the stakeholders in each stage of the building life cycle will use different terminal equipment, such as workstations, laptops, tablet, phone or sensor, etc., these devices will visit different web-based applications at the center of the cloud. These applications based on BIM development contain building design, construction operations management and other professional building application. Besides, it also contains the ontology-based web information retrieval App and the mobile devices App.

The user can rent cloud services from cloud service provider according to their own requirements, and pay according to the service types and time, namely SaaS.

4. Cloud Deployment and Information Interoperability Process

4.1. Hybrid Cloud-Based Deployment

This paper will apply a hybrid cloud approach to deploy the architecture (see **Figure 2**). The idea show as following: Public and private clouds are isolated through the firewall. Public cloud stores base model libraries related to construction projects and various parties' public data which will form a domain ontology library through transformation. In addition to interactive data in the public cloud, various applications offered by cloud service providers are also contained. Construction project single participants (via a private cloud, internal interaction) or multi participants (via public cloud, multi-interactive) can retrieve and process these applications and data. Participants will automatically realize the extraction and combination of the process-based service through semantic analysis, based on their business needs, which can not only improve the efficiency of data retrieval and architectural model usage, but also ensure real-time transparency of public data and safety and security of private processes. AS this solution combine the private cloud of the intranet and the public cloud of extranet to fix the issue about construction information exchange, it can be regarded as an application of hybrid cloud.

4.2. Cloud and Open BIM-Based Building Information Interoperability Process

The information interaction process involves multiple stages, such as project planning, design, construction, operation, etc., and each stage builds the BIM sub-models in the different process of the project. Then different participants realize the data extraction, extension and integration according to the specific business requirements. Thus, the BIM sub-models continuously develop and evolve, so as to serve different application subsystems. Based on the specific business, the modeling process of information interaction can be shown on **Figure 3**.

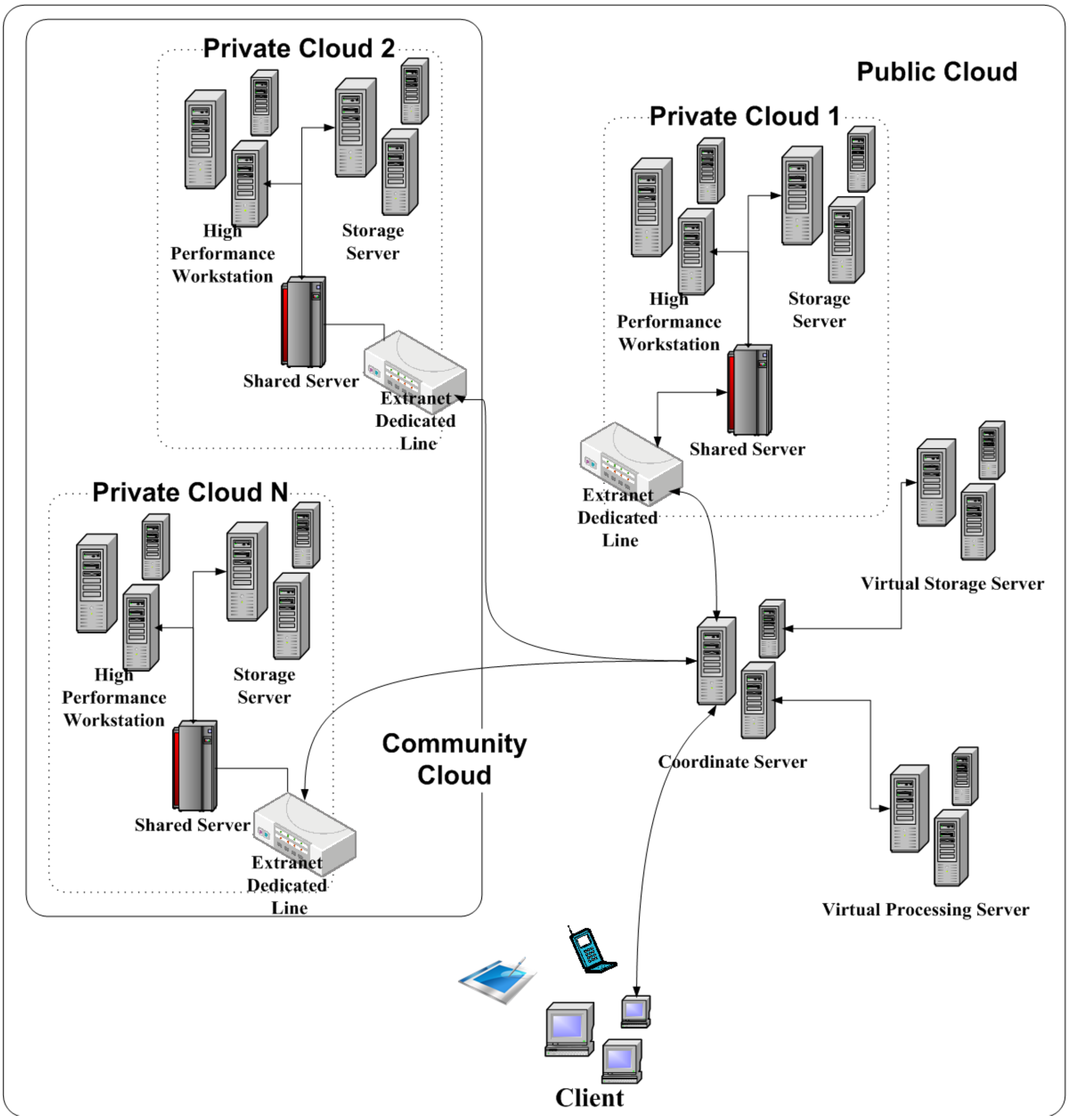

Figure 2. Hybrid cloud-based deployment architecture.

First of all, the project participants based on the specific needs of the business use computer or other mobile devices connect to the Internet and access to the related applications in the cloud platform. According to the specific application, determine whether to call the internal data on the private cloud. If need, then authorize access to the related internal database. If need not, specify the business requirement on the cloudy platform. In the following step, determine whether the specified business has the IDM process specification, and establish the IDM standard according to the business requirements. Then, according to the IDM specification, extracted the BIM model from BIM database. If there is not established business model, it is need to import the IFC files to process modeling according to the IDM process specification, then integrate the sub-models into BIM database.

5. Case Analysis

Recently, with the improvement of Shanghai railway transit construction networks, the difficulty of construction projects is also increasing. In the situation that underground projects are buried deeper and geological conditions

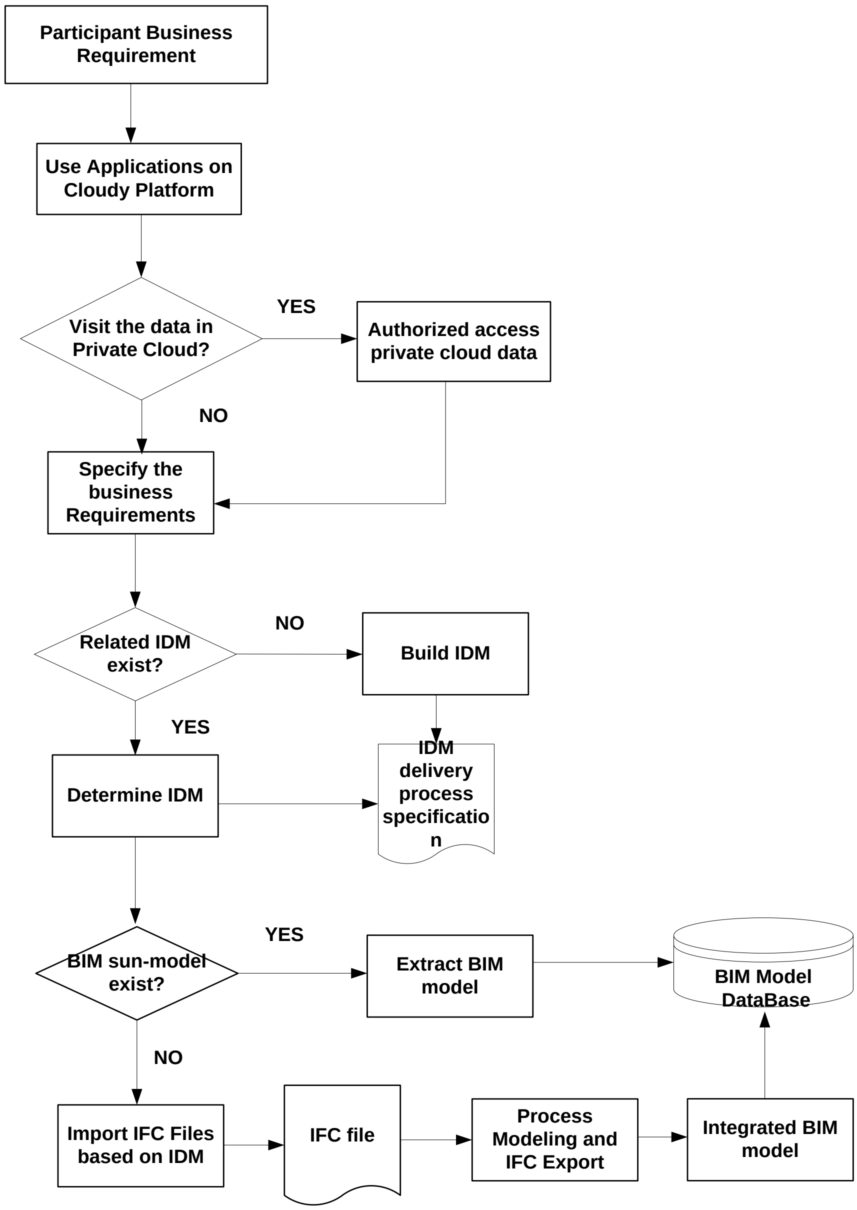

Figure 3. Cloud and open-based building information interoperability process.

are more complicated, how to effectively control the tunnel leaks, ensure project quality and effectively prevent construction risk to stop security incidents have become an important subject for the current project control. In the past research, the BIM-based information management system in the underground tunnel construction has been conducted [16], however, cloud-based Open-BIM building information interaction model will become a new and efficient technology. Take Shanghai Metro Line 12 Project 11 as the application object, the following requirements could be realized using the new technology: the real-time management to realize the quality, safety and supplies of the project; enhance the quality, safety and traceability of materials management; real-time control of the project quantity machine plan and the actual consumption analysis; linkage calibration analysis emphasizing the multi-subsystem; detect and alert project risk timely; the goal to remotely and intelligently show project running integrated data. The above research can realize and implement tunnel construction management work platform.

According to the interaction framework proposed in Section 3, Cloud-based Open-BIM Tunnel Construction Information System is shown in **Figure 4**. The infrastructure layer of the system can take advantage of external system, such as personnel positioning system, segment quality system and shield advance system, and collect the information about personnel positioning, segment quality and shield advance into virtual cloud space during the real-time dynamic construction process. The data layer applies heterogeneous data integration mechanism and integrate the information about personnel positioning, segment quality and shield advance into the BIM model and central database through data interface adapter. Such data can be read, used, modified and stored in the data layer based on a certain way. The model layer can read, retrieve, integrate and show IFC model data through the BIM data integration platform. It is able to organize the data from the layer organically to form a model equipped with characteristics and present data under different perspectives against various conditions of construction sites. The service layer can help to integrate and manage each model of the whole system. In addition, guaranteeing the operation of each function module successful is another contribution. The service layer is the link between the user application interaction layer and the model layer. It is also a layer to show the specific function and application of real-time intelligent monitoring platform, including real-time dynamic display to

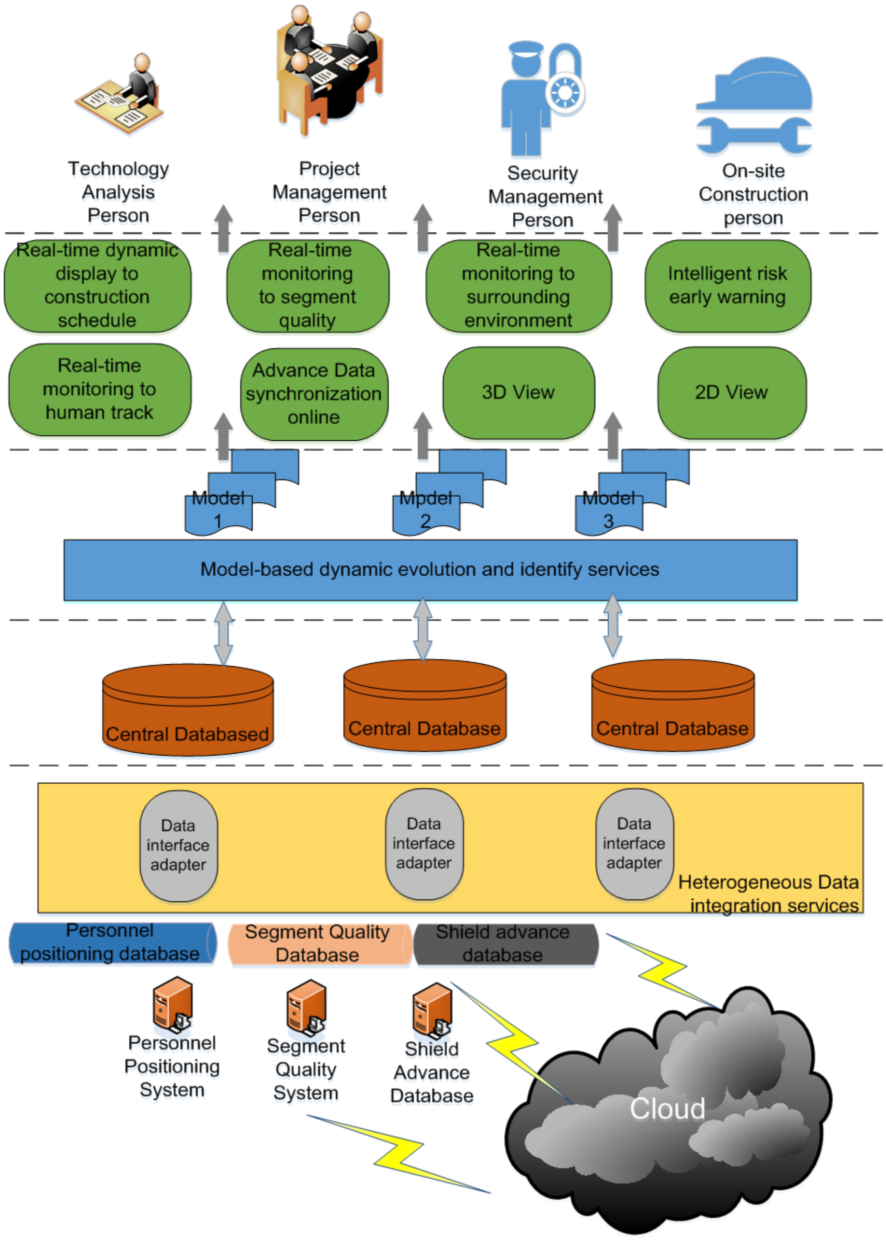

Figure 4. Cloud-based Open-BIM tunnel construction information system.

construction schedule, monitoring to surrounding environment, monitoring to human track, monitoring to segment quality. Due to the corresponding BIM model, the service layer can gain the required model data, share data and apply various application systems based on BIM technology by the distributed operating mode that network technology supports each participant. The application layer mainly realizes the human-computer interaction interface.

The system is deployed around the construction process. Different types of users can conduct remote real-time construction risk monitoring through the corporate virtual private cloud. Tunnel Construction Collaborative Platform Interface is shown in **Figure 5**. Human track system, segment management system and shield advance system (deployed in the private cloud) can automatically transfer the data collected from the underground and aboveground to the core database of the site (deployed in the public cloud) by data collection device. Digital shield tunneling construction systems engineering platform can monitor construction schedule, construction

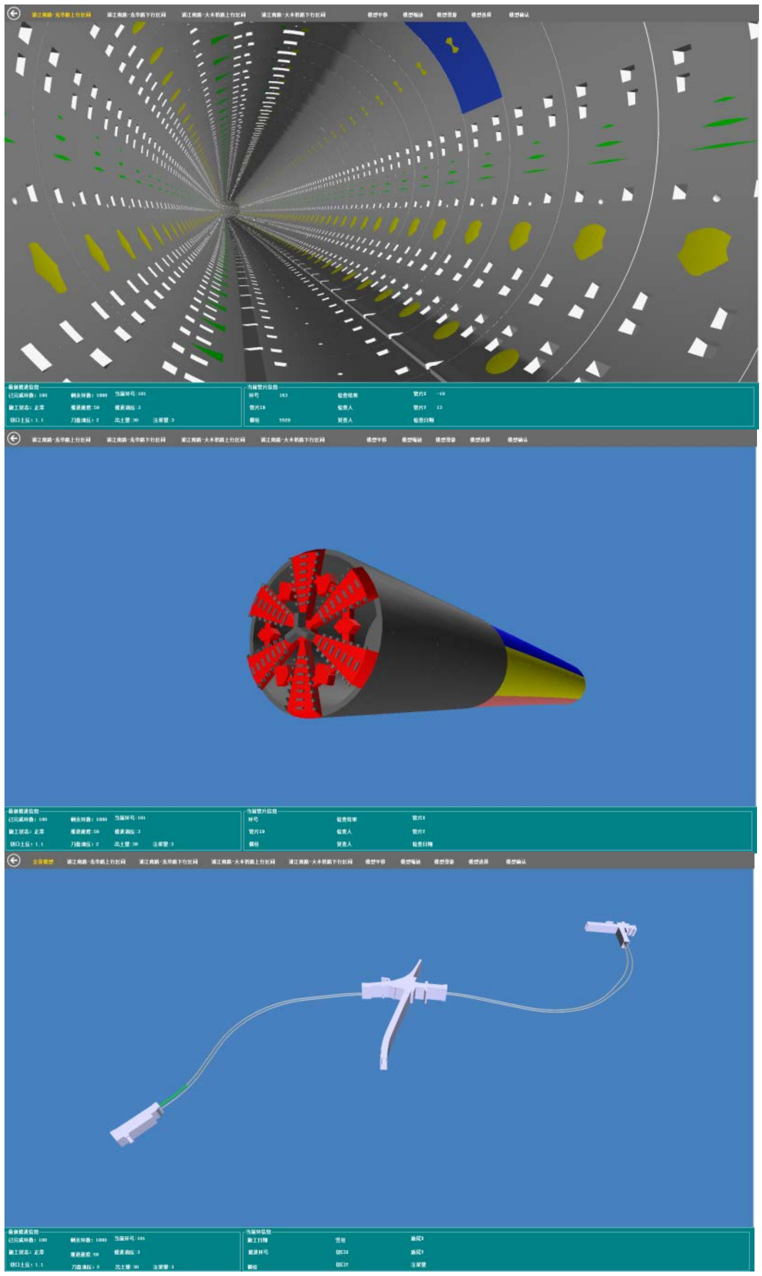

Figure 5. Tunnel construction collaborative platform interface.

quality and personnel security dynamically as well as identify, estimate, warn and control risks through BIM model. When the risk is greater than the warning line, the system will alert to the user by BIM model. Users can develop a detailed understanding of the process of risk formation, a further analysis of risks and a solution through the online early warning data of the model.

6. Conclusion

Cloud technology supports virtualization and QoS (quality of service), owns high reliability and scalability, and facilitates the multi-user collaborative interaction in distributed systems environment. Open BIM, as the standard of building information sharing and exchanging, contributes the interoperability among the heterogeneous data and applications in the whole life cycle of building. Based on the cloud and the Open BIM, the research analyzes the could service mode of building service, puts forward the building information interoperability framework, explains the detailed cloud deployment and illustrates the building information interaction process. Finally, the case of the tunnel construction collaborative platform provides the trend and guidance to the research and practice of information interaction in the AEC industry.

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