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Application of Cloud Storage on BIM Life-cycle Management

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Abstract Because of its high information intensity, strong consistency and convenient visualization features, building information modelling (BIM) has received widespread attention in the fields of construction and project management. However, due to large amounts of information, high integration, the need for resource sharing between various departments, the long time-span of the BIM application, challenges relating to data interoperability, security and cost all slow down the adoption of BIM. This paper constructs a BIM cloud storage concept system using cloud storage, an advanced computer technology, to solve the problem of mass data processing, information security, and cost problems in the existing application of BIM to full life-cycle management. This system takes full advantage of the cloud storage technique. Achievements are reached in four areas of BIM information management, involving security and licensing management, file management, work process management and collaborative management. The system expands the time and space scales, improves the level of participation, and reduces the cost of BIM. The construction of the BIM cloud storage system is one of the most important directions of the development of BIM, which benefits the promotion and further development of BIM to better serve construction and engineering project management.

Keyword Full Life-cycle BIM, Mass Data Processing, Information Security, Information Collaboration

1. Introduction

Building information is present through the whole life cycle of the engineering and construction phases. Due to the long time period and the numerous contractors, the phenomena of mass information and information attenuation occur throughout the life cycle [1]. The traditional methods of information exchange cannot meet the mass information processing requirements of modern large-scale construction projects. To improve the efficiency of information management, the idea of building information modelling (BIM) was proposed in the 1970s [2]. Detailed definitions are given by Charles Eastman [3], Jerry Laiserin [4] and McGraw-Hill construction [5]. "A Building Information Model (BIM) is a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle from inception onward. A basic premise of BIM is collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM

process to support and reflect the roles of that stakeholder." defined in the National Building Information Model Standard (NBIMS) [6].

BIM ensures information accuracy and consistency, resolves the problems of information isolation and discontinuity between the contractors [7]. The visualization feature changes the way the participants work, improves the efficiency of the life-cycle management and enhances the enterprise value [8-9]. However, the convenience and the application of BIM are limited because of the huge amount of information, the high integration density, the high cost of the existing hardware, the large amount of participants, the complex interoperation of information and the long life-cycle. In order to instruct, promote and track the implementation of the BIM technique in the construction industry, to solve technical and practical problems, and to enhance the utilization of BIM within the whole industry, China Exploration & Design Association hosted a BIM lifecycle application seminar in November 2012, which brought forward the discussion of BIM life-cycle management in the construction trade [10]. This paper discusses the use of cloud storage in BIM life-cycle management, aims to solve the problems caused by massive information and complicated categories, provides theoretical support and reference for further practice.

2. The requirements of cloud storage for BIM

2.1 Features and problems of BIM

BIM benefits the fields of engineering and construction in the following respects: At the design stage, BIM provides a 3D visualization technique. Designers can show the full building more intuitively and achieve a professional collaborative design, which can be used for collision tests, scheme comparisons, energy consumption analyses, and so on [11-13]. In the project construction phase, 4D construction management (time analysis) allows for an integrated dynamic visualization. The functioning and constructiveness of the project can be predicted through the simulation of construction methods and processes, which greatly improves the efficiency of cost, quality, and schedule management [14-16]. In the operation stage, BIM can be used for accurate building property management, and the intelligent management and maintenance of equipment. The operators can perform active and automatic project maintenance and management throughout the whole life-cycle of the project [17-21].

On the other hand, BIM brings new problems as well as improving information management [22].

(1) The participants in construction project are numerous, including the owners, the reconnaissance units, the design units, the design organizations, the construction units, the supervision units, the government departments, the operation units, and the management units. The lack of a unified data processing method makes the exchange and interchange of information difficult [23-25]. For example, at present, when discussing a specific construction program with BIM files, the construction, supervision and construction units have to hold a meeting, at a given location, around a computer. Remote collaboration is not allowed. Construction information cannot be reported to BIM daily on time.

(2) The amount of information generated at the construction stage is large [26]. The size of the BIM data files can easily reach dozens or hundreds of Giga-bytes. The BIM software and computer hardware meeting the requirements placed on them is critical. Mobile workstations or high-end desktops with expensive costs are generally used. Each BIM user has to be equipped with a high performance computer, since it is not a collaborative network. When the users need to consult multiple BIM files, it is difficult and inconvenient [27]. Singh, Vishal, Gu, Ning, Wang and Xiangyu have studied this problem in Australia and proposed a solution similar to DMS (document management systems) that BIM files are shared on the server, users can upload and download BIM information files according to their level of access [28].

(3) Because of the large initial investment, corporate leadership will be very cautious when making decisions, which limits the application of BIM in industry. [29] At present, there are mainly three kinds of domestic BIM software systems. The general software which costs tens of dollars per set, can be used for general purposes such as designing and construction. The secondary development software customized for special demands costs a lot. The follow-up training fee, service fee and software upgrade costs can be as much as hundreds of dollars. A BIM consulting report can be provided by consulting companies at a cost of hundreds of dollars. All of the risks restrict the applications of BIM.

(4) From the whole life-cycle perspective, construction information includes comprehensive information such as a feasibility study, decision-making, design, planning, supply, implementing, controlling, operation management, and so on. From the project management perspective, construction information involves cost management information, schedule management information, quality management information, contract management information, etc. From a single project perspective, construction information contains objectives, subsystems, resources, information, activities and organization information, etc. BIM is an effective solution

to information integration. However, there is no effective way to store the large amount of information in a centralized classification. This presents new problems such as efficiently reading and transferring information [30].

(5) From a security perspective, the current BIM is designed for information integration and management based on digitalization and visualization techniques. There are licensing and security issues between various participants, different departments and different projects. Therefore, one of the key challenges is how to quickly and accurately access the information with permission [31].

2.2 features of cloud storage

In order to solve the problems discussed above, we propose to create a BIM using the cloud storage technique. Cloud storage is an extension of cloud computing, which collects, stores, and processes data based on services. Cloud storage is the basis for cloud computing systems such as the cloud platform, and cloud services [32]. The native natures of cloud storage as listed below make it a great solution for the difficulties in BIM [33].

(1) Expansibility. Cloud storage provides a huge resource pool. The use of resources has a different duty cycle. Dynamic retractability control can significantly improve the effective utilization of resources. At a high load, resources are dynamically expanded, while at a low load, excess resources are released. The problem is solved using scale expansion technology [34]. This is particularly suitable for investigation and design units. The results and resources of these units, especially the BIM information, are scalable, which demands organic expansion, not a simple collection.

(2) Convenience. Cloud storage makes cross-regional, cross-company work possible. By deploying local BIM applications and BIM files in the cloud storage system, the participants can access, modify, and manage information from a terminal without time and space limitations [35]. Clients provide feedback on user's operation information to the cloud platform, while the cloud provides feedback to the user in the form of operating interface pictures, so users do not have to download the model to revise and upload it. (Figure 1) This is a revolution for engineering information management systems, adopting tens, hundreds, or thousands of projects.

(3) Collaboration. The cloud storage system guarantees real-time collaborative work between the participants. Both in the design phase and the construction phase, BIM can exponentially increase the efficiency of information communication. BIM Cloud storage is designed to provide the possibility for "instant cooperation".

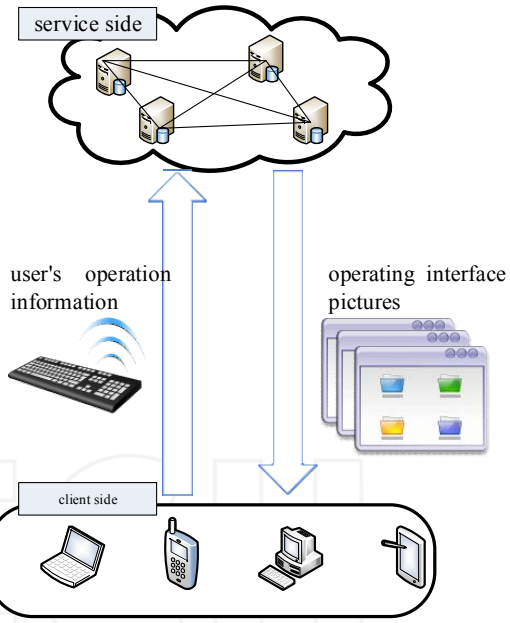

Figure 1. Cloud services principle diagram of the implementation

(4) Low cost. The cloud virtual server is highly cost-effective. At the same time, cloud storage can also reduce the investment required for developments, maintenance and management later on [36]. More cloud storage users will lead to lower costs.

In summary, the expansibility of cloud storage can solve the BIM information overload storage problem. Enterprises can expand the system quickly, without purchasing expensive servers, and convenience for the client and collaboration can promote cross-regional, cross-company cooperation between various participations. Reliability can ensure the security of BIM information sharing. The low cost can reduce the cost of BIM system construction, and boost the promotion and development of BIM in the field of construction. In conclusion, cloud storage, an advanced computer technology, can be used to construct BIM cloud storage systems, to solve practical BIM problems. The motivation for developing the BIM cloud storage system is shown in figure 2.

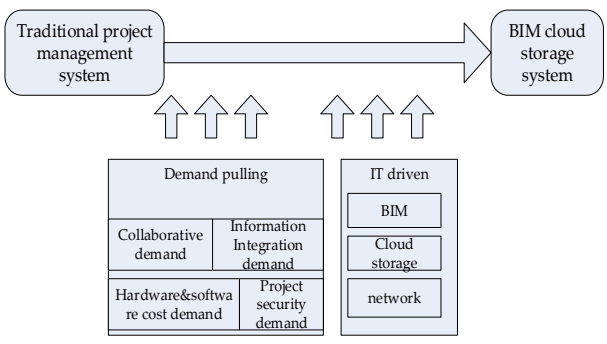

Figure 2. BIM storage mechanism diagram

In order to ensure the portability and interoperability of cloud storage system, even if we use the form of cloud platform that transmits operation interface pictures to the client, we still need to limit the access to the cloud storage system network accordingly. Smoothness of user action is ensured when the connection speed at each terminal is 2M or more. Therefore, attention is needed in order to make the cloud storage system platform server network environment the best over 100M, and more than 2M or more optical networks should be set up for every client network environment.

3. Literature review

In the past 15 years, BIM has changed the industry chain in the construction trade to a certain degree. It was predicted that BIM would bring great innovation when the cloud age would come. Little Diversified Architectural Consulting, a company located in Charlotte NC, built a private cloud which is the first ACE workstation cloud in production. This cloud is built to spread BIM usage. Its cloud workstation has 11 business benefits, such as the fact that it can be implemented across regions and across companies, and its integration IT infrastructure cost [14]. CarbonBuzz, a cloud computing platform advocated by RIBA and CIBSE, funded by governments and the construction trade in 2007, makes its members test their carbon emission index, manage the risk of their buildings and share their experiences anonymously [37]. For the sake of intelligent building, Longdhua first proposed an energy management and control platform in cloud computing, provided supplies and services for energy management and control platforms in cloud computing, provided self-adapting control systems based on an IP controller [38]. In June 2011, the company, Autodesk, released a new generation BIM solution, Autodesk BIM 360, which brought BIM procedures to the cloud, provided professional cloud services to civil engineers, to transportation and urban planning professionals. In September 2011, Autodesk issued AutoCAD, an online CAD software providing an updated cloud service. This software was designed especially for designers and engineers in China, supported the creating and editing of online CAD files and had basic functions such as drawing, editing and labelling. In December, Autodesk opened CADer, a portal site providing AutoCAD software, information and app stores in mainland China. This website provided a DWG editor, had online stores selling professional materials and applications, supplied cooperation services and a community platform [39]. In December 2011, Autodesk acquired the company, Horizontal System. Techniques from Horizontal System improved the Autodesk 360 for BIM and helped Autodesk develop BIM for a cloud platform [40]. In Be Inspired in November 2011, the company, Bentley, released an updated software: Generative Components (GC) and Bentley Connect. These were SaaS --- rudiments of the cloud strategy [41]. Wei Wu and R.R.A Issa (2012) mentioned that they employed BIM cloud computing to implement the automation of energy and environmental design [42].

Currently, BIM software is mainly designed for one particular company, one special group of people or one special period. For example, Autodesk cloud and AutoCAD are used in the design period. Whereas, the CarbonBuzz cloud computing platform is used to ensure energy efficiency in building budgets. There have barely been any developments of BIM cloud storage systems for various members across the whole life-cycle of the project. Moreover, companies develop their own BIM cloud storage systems using their own framework. These systems are different and greatly limit communication and information distribution [43]. It is not easy for BIM to implement information sharing in the construction trade. On the one hand, since the life-cycle of one project can be as long as several decades, there would be different members and diverse pieces of BIM software. On the other hand, software updating and new functions increase hardware costs, which adds more obstacles to promoting BIM [44]. Therefore, based on the life-cycle of projects, this article presents a BIM cloud storage system, aiming to develop a better BIM.

4. Life-cycle BIM cloud storage framework design

The cloud storage system proposed in this paper changes the current modes of communication from point-to-point to integrating and sharing, which help improve the level of transparency, increase the speed and accuracy of information transmission and decrease the cost within the BIM purview.

Meanwhile, an approach mixing active and passive information is added to the original passive mode. As the cloud storage has integration and separation functions, users can obtain the information when the platform releases it. Moreover, users can also quickly query and locate the information according to actual requirements.

Cloud storage is classified as public cloud, private cloud, hybrid cloud or community cloud, depending on the means of service. Private cloud is defined as a storage platform which affords a corresponding service to a construction enterprise or a project with integrated resources. Furthermore, it also provides the most effective means of controlling data, security and QoS (Quality of Service) [45]. The private cloud based storage system we proposed consists of the following five layers, as figure 2 shows [46]:

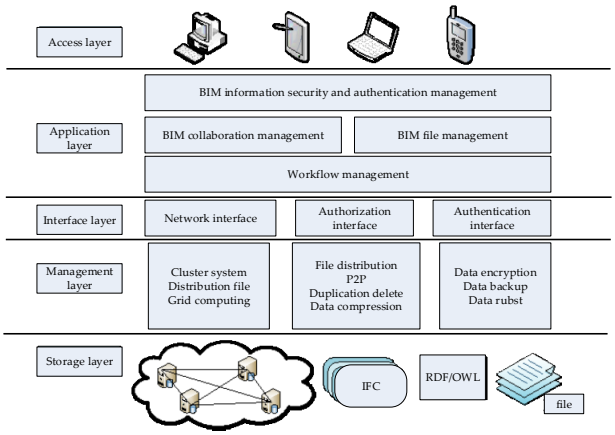

Figure 3. BIM cloud storage block diagram

4.1 Storage layer

The integrated management of massive amounts of construction information is a primary question during the construction life-cycle process. The storage layer is the fundamental part of the BIM cloud storage and the basis of the entire system which aggregates all the construction information. Its component units could be IP (Internet Protocol) devices such as fibre channel storage, NAS (Network Access Server) and ISCSI (Internet Small Computer System Interface) storage, and DAS (Direct-Attached Storage) storage such as SCSI (Small Computer System Interface) and SAS (Serial Attached SCSI) is also included. The massive distributed cloud storage devices can be connected by WAN (Wide Area Network), Internet or fibre channel networks, and unified management system is equipped to provide logical virtual, integrated and multi-link redundancy management, while also serving as a means of carrying out inspections, maintenance and upgrades.

4.2 Basic management layer

The basic management layer is the core of BIM cloud storage and the most difficult part to achieve. The basic management layer allows many BIM cloud storage users to cooperate together and creates better unified data access by means of the distributed file system and the grid computing technology of the cluster system.

The cluster file operating system is used by the cloud storage system to perform back-end cluster action. It carries out data distribution, processing and feedback using a control unit and a management unit. With the help of a CDN (Content Delivery Network) distribution system, P2P (Peer to Peer) and data compression technology, the BIM cloud storage can work effectively with less space and a lower transmission bandwidth.

The basic management layer provides secure access and transmission to BIM data storage. Data backup and disaster recovery technology ensure the security and stability of the BIM data.

4.3 Application interface layer

The application interface layer is the most flexible part in BIM cloud storage. Using certain open application interfaces, different BIM software suppliers can develop their own application service with the unified interface of the application. Users can choose more suitable interests for their application service. According to the type of business, the storage development unit can provide different application services and interfaces. It can easily develop and extend the application of the storage, such as the cost, schedule, its infrastructure and property management, without any changes in the storage system.

4.4 Application service layer

As long as authorization is provided, every unit of the project can enjoy services such as information management of security, workflow, information files and collaboration with other users through the management interface.

4.5 Access layer

For project participants, the access layer is the direct interface to the cloud service, which uses a PC, a tablet PC, a virtual desktop, a mobile phone, or even a cloud terminal or program as its access devices. The cloud terminal focuses on communication protocols and security between the terminal and the cloud. With different access terminals, the users can participate in remote collaborative work at any time and any place, and telecommuting improves the operational capacity and efficiency of the project since distributed telecommuters ensure the 24-hour operation of the project.

5. The introduction of the BIM cloud storage system function

The BIM cloud storage system function frame contains four parts as follows: BIM information security and authentication management, BIM information file management, workflow management and collaboration management.

(1) Information security and authentication management

BIM cloud storage system has established the effective information security protection mechanism and access management, which mainly includes user logins, access settings and professional information settings, etc. The execution of information security and authentication management depends on user's identity authentication and file permissions.

Especially for major information queries, one participant can limit the access of other professionals by setting the level of access authorization. Therefore, we can prevent the disclosure of important information when we are sharing information. For example, the settings that the owners use and the level of access required to view budgets and investment information; the settings that the construction unit operates and the level of access to detailed schedule information that should be compiled by the construction unit; the settings that the owner and the supervision company use to verify the level of access. By taking advantage of BIM information security and authentication management modules, we can easily access data files used by the database system to support better file management. In the system, the efficiency of the file management will be improved to adapt to the need to change from construction project management to construction information model based management which has its foundations in future further development.

(2) Information files management

In order to deal with the highly integrated nature of various types of information of massive amounts on a BIM platform, it is necessary to establish a highly efficient construction project files management module appropriated to the BIM environment. With this management module, we can implement BIM file sharing, upload, download, query, edit and control the function of documents.

The BIM information source file has the following stages:

1, the design stage: a design institute authorized by the owner assigns a number of professional designers who, according to government regulations, set the standards and specifications, as well as requirements that the owner must complete. At this point, the basic BIM design files plus were formed so that the design institute would have entry to the cloud storage platform. The owner takes the BIM design files' attached budget information.

2, the construction stage: construction units acquire BIM design files from the cloud storage platform provided by the design institute to deepen the design, increase the schedule and adjust the BIM files in the construction process according to the site's need. In the process, if it belongs to design changes, you can carry out design change synergy management in a BIM information synergy management module. At the same time, material suppliers, and equipment and supervision units can add their own information, such as tables containing engineering or material properties, receive reports, completion reports and other items concerning engineering construction progress. Owners keep track of BIM information file changes in the process to improve the efficiency of the management of field work.

3, the operation stage: the operation period, generally for decades , which will be subject to a lot of use and require maintenance information. The main sources are owners and vendors. We usually use BIM file components such as attached document information including equipment repairs and maintenance information for storage, then the dynamic BIM information will last for decades or even longer.

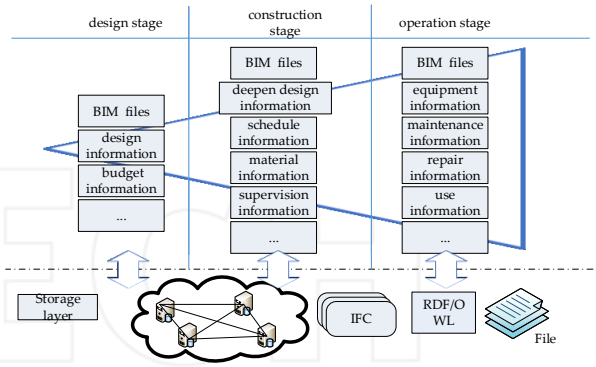

Figure 4. Use of cloud storage technology effectively in the life-cycle management of BIM

For many to be able access BIM files in a BIM cloud storage system, the system will only display information with the user's permission. For example, in the processing of a specific construction project, if the BIM file information system includes a number of pieces of construction information such as building, supervision and project information, the construction unit can query the relevant construction information according to the levels of access authorization across the system while confidential information is denied, such as investment, costs and so on, which require the user to login if they are to be accessed in the system.

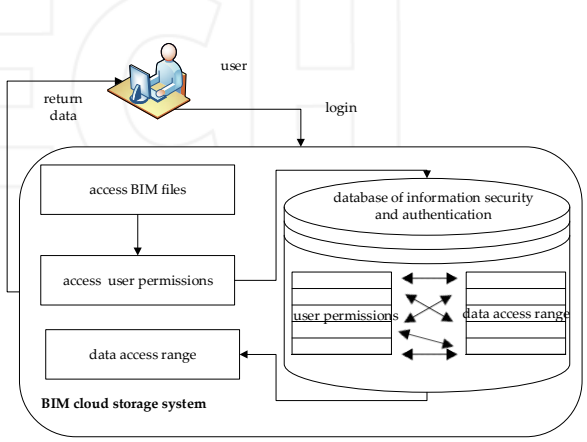

Figure 5. Access BIM files on BIM cloud storage system

(3) Workflow management

BIM cloud storage system workflow management includes workflow templates, project workflow customization, workflow control and so on. In the

workflow management functions, the project workflow is supported by flow definition and modelling, flow operation control and interaction with the outside to maximize the workflow automation.

For the workflow template, BIM cloud storage system predetermines engineering process templates, such as the design of the examination, a change of negotiations and a construction scheme of the common audit workflow. For workflow customization, user-defined workflows are supported and worksheets are customized, and staff responsibilities and engineering phases can be transferred, etc. while for workflow control, by using the workflow engine assisted progress, log files can automatically be generated including the processes of all the parties involved with a reminder function. Taking the change of the design as an example, if the owners have the intention of putting forward changes to the design, they can propose requests in the system to the BIM information model, and the system will automatically register and then save the information. At the same time, the BIM information will be transferred to the project parties involved, and then the project management will agree to consult and offer advice. Finally, when the designers amend the design, project management, construction and suppliers discuss and approve it. As we see, all these processes are completed on the system platform while all the distribution is implemented automatically at the same time.

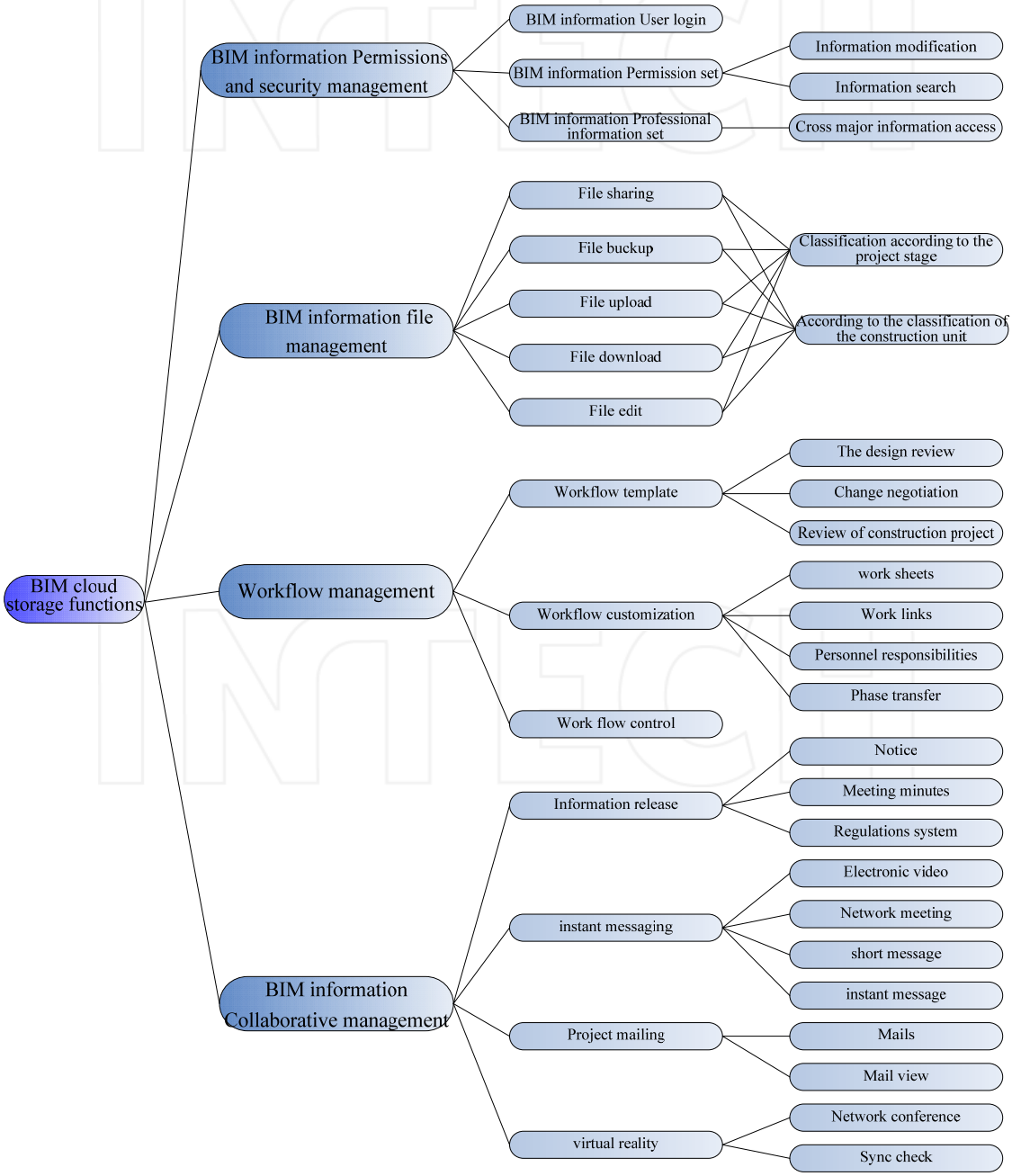

Figure 6. BIM cloud storage functions

(4) Information collaborative management

BIM collaborative information management includes project information publications, instant messaging, project emails, virtual reality displays, etc. and during the use of the information exchange function, the information is mainly composed of notices, meeting minutes, ordinance systems, texts and so on. Project participants can gain timely access to project information which provides a convenient platform for cross-regional exchanges in the form of the electronic bulletins released. The instant messaging is mainly composed of four parts, which are electronic video, web conferencing, SMS, and timely messages, and participants can hold discussions and dialogues on the project by video voice, video switching and sharing, electronic video and web conferencing. It can also provide online reminders and support various forms of file transfer by mobile phone text messages and instant messaging. Project messages may include notices of meetings and work schedules by sending, receiving, replying and saving emails to the addresses of all the participants. Virtual reality imaging is used throughout the entire multi-dimensional virtual model and environmentally supported module of the BIM collaborative management module. If there are design changes that arise in the online discussion, with their computers, the parties can enter the network and discuss the module of the BIM cloud storage system which supports video calls and instant text messaging, while the IM model also displays screens synchronously. Thus, participants can easily carry out discussions of design changes within this virtual reality display.

6. Conclusion

In this paper, considering the BIM security and permission problems brought by BIM characteristics and its lack of integrated and classified storage, lack of a unified mode of communication, common BIM management software and the high cost of hardware, we propose a new cloud storage method for BIM management which establishes a BIM cloud storage system to break through the constraints of BIM applications.

The BIM cloud storage system which this paper proposed, combined the characteristics of BIM with the storage layer, infrastructure management, application interface layer, application service layer and access layer to build a better system and environment, to achieve four functions, which are, namely, the management of BIM information security and authentication, BIM information documents, workflow and BIM collaboration. The services provided by BIM cloud storage systems enable users of different locations to easily access cloud BIM, which greatly improves collaborative work and is able to effectively reduce costs at the same time. The massive management and storage of information in the cloud can solve problems of information burdensome and the difficulties of information security management arising due to the information centralization brought about by the BIM. The establishment of the BIM cloud storage system provides new possibilities and directions for BIM to gain in popularity across the whole engineering industry, and it ultimately improves the performance of the services of BIM in the whole construction industry. This will create a great impact in the promotion of the management of all the digitized and engineering information and development of the construction industry. Currently, there is no cloud storage which contains a high-performance diversified graphics workstation established in China, and the cloud applied by LITTLE was first used as a cloud storage abroad but only as an AEC workstation in the cloud.

It can be predicted that the creation of a BIM cloud storage system is the perfect combination of the latest computer and building information technology, and it will be bound to play a significant role in promoting the application of BIM and cloud computing as a successful, typical application. In a word, a BIM cloud storage system will create a larger space for the development of BIM.

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