Research on the Efficiency of 3D Collaborative Design Based on P-BIM Cloud Platform

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Abstract. With the further development of the construction industry, the types and functions of buildings have become more and more complex, so it's particularly important to effectively improve the efficiency of architectural design. The value of BIM has been widely recognized by the architectural design industry, but the information of the model can't be effectively exchanged, which causes the failure of BIM to play its due role in improving the efficiency of collaborative design. Therefore, the reasons why information exchange is impeded on the BIM application are analyzed first through the application status of collaborative design and then it is concluded that the format of BIM software is not compatible and the model data transmitted is too large are the main obstructing factors for implementing BIM on three-dimensional (3D) collaborative design. Based on this, the current research describes the theory of building a 3D collaborative design platform and the P-BIM cloud platform developed based on this theory. Next, the building information model of a dormitory in Shenzhen University was used as a case to carry out the verification experiment that the 3D BIM model data of the dormitory was transmitted through the P-BIM cloud platform. Experimental results show that the P-BIM cloud platform can effectively implement information exchange in architectural design and reduce the repetitive work in the work handover to improve the efficiency of architectural design. Finally, some suggestions on the application of BIM are proposed according to the research results.

Keywords: Design efficiency · Collaborative design · Information exchange · P-BIM cloud platform

1 Introduction

In terms of cost, architectural design has the greatest impact on the whole life cycle of construction projects. Data shows that the influence of the architectural design on the cost can reach up to 75%–95% [1]. With the development of the society, the type of construction projects and functional requirements become more and more complicated. The requirements for designers have become even higher. Therefore, effectively improving the efficiency of the building design is particularly important.

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In recent years, the informatization level of China's construction industry has gradually improved and the application value of BIM in architectural design field has been recognized by government, industry organizations, software developers and other participants [2]. Ministry of Housing and Urban-Rural Construction of the People's Republic of China (MOHURD) has issued the 13th "five-year plan", namely "the outline of informationization construction in 2016–2020", which explicitly proposed to comprehensively push the informationzation process of the construction industry and strengthen the integrated application of BIM capability. The plan has also put forward that the survey and design enterprises should "speed up the general application of BIM, and realize the technological upgrading of survey and design". In 2012, China Academy of Building Research (CABR) has united several companies to establish the "China BIM Union (CBIMU)", which aims to promote BIM application and support the development of Construction industry. National standards related BIM have been published, such as "Unified standard for building information modeling GB/T", "Standard for building information modeling in construction GB/T" and "Collection of standards for P-BIM software function and information exchange of building engineering" and so on. According to the "Research Report on the value of BIM application in China - 2015", in terms of the benefits created by BIM [2], the survey shows that 69% of the design companies think BIM can optimize the design scheme, 66% think BIM can reduce the error in the construction map, 61% think BIM can improve customer participation, 55% think BIM can reduce the construction site coordination problem, and 52% people think BIM can reduce the rework. Software companies have also started to develop BIM software. Some companies have successively developed software-based BIM software integration application platforms, such as Bentley, Revit and Tekla.

With the continuous study of BIM, the definition of BIM is gradually clear. Definition of BIM more recognized in the world is from the buildingSMART, including three meanings: 1) Building Information Modeling: a BUSINESS PROCESS for generating and leveraging building data to design, construct and operate the building during its lifecycle. BIM allows all stakeholders to have access to the same information at the same time through interoperability between technology platforms. 2) Building Information Model: the 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 onwards. 3) Building Information Management: the ORGANIZATION & CONTROL of the business process by utilizing the information in the digital prototype to effect the sharing of information over the entire lifecycle of an asset. The benefits include centralized and visual communication, early exploration of options, sustainability, efficient design, integration of disciplines, site control, built documentation, etc., effectively developing an asset lifecycle process and model from conception to final retirement [3]. BIM is a Shared digital expression of the physical characteristics, functional characteristics and management elements of an engineering project or its components, mentioned in the "Unified standard for building information modeling GB/T". In either definition, the ultimate goal of BIM is to realize the data sharing of the whole life cycle of the construction project. Therefore, the core value of BIM is to realize information exchange, means sharing of information over the entire lifecycle of an asset, and improve collaborative work efficiency.

The biggest problem affecting the value of BIM in the field of architectural design is also data interaction [2]. According to statistics, the current use of BIM software in the architectural design stage can reach 60%–80% [2], but only a small part of the functions of BIM are actually applied. Almost all applications are based on the five basic functions of visualization, coordination, simulation, optimization, and graphing of BIM software. In the process of architectural design, the model data of each profession is still in the state of "information island". The task of construction design has become more and more complex. The number of texts for a common single-item project can be as large as 104 [4]. Therefore, deepening the application of BIM in the architectural design stage and using BIM to help optimize collaborative design to achieve data sharing in the architectural design stage is an important method to improve the efficiency of architectural design.

2 Literature Review

2.1 Information Exchange Based on BIM

There are many theoretical researches on the information exchange about BIM. And most of them are based on the current international mainstream IFC standards for extended applications and the exchange of model data. The IFC standard uses object-oriented design ideas to express building information, using the entity data type as the smallest unit of information for describing reality. Its data model structure is divided into four functional levels, including the resource layer, core layer, interaction layer, and domain layer. CABR and Beijing University of Aeronautics and Astronautics completed the IFC interface writing of PKPM software and achieved data conversion between BIM basic software and PKPM software [5]. Mahmoud et al. developed the AEC Agent model for IFC-based information integration and described its implementation using a scaffolding system as an example. Agent modeling was implemented by adding IFC entities [6]. Plume et al. discussed the collaborative design of different professional IFC-based architectural models, and focused on the technical operational issues in the design process [7]. Yusuf Arayici proposed a method based on the design of interoperability specification performance through case study method, which made the design more flexible and reduced the transfer of redundant data during the design process [8]. The IFC standard has good scalability and a huge system, so the integration and application relationship is complex. Unless there is a clear procedure or discussion between the participants to clarify the accuracy of the exchange of information, IFC mode can't automatically call the model information to determine the accuracy. That is, the information that should be encapsulated in the IFC mode needs to be clarified. Otherwise, some specific information will be omitted during the exchange process [9, 10]. Although there are many researches on information exchange for BIM implementation, there is still no effective way to solve data sharing.

2.2 Architectural Design Efficiency

In order to improve the value of information in the collaborative design and reduce the workload, as well as to solve the problem of data redundancy in the IFC model, Guining et al. developed corresponding tools to extract the sub-model of the IFC model to increase the data value density of the sub-model and simplify the processing of the IFC model complexity. The application shows that the sub-model for data extraction based on domain model information requirements has a higher value density than the IFC-based sub-model data [11]. Ayako et al. analyzed the development work of the IFC standard in the field of structural design, and made relevant assessments that the IFC standard theoretically meets the data requirements of the structural design. In fact, because each major software company uses its own database to interface with its display platform, the database is not built according to the format of the IFC standard. As a result, when different software exchanges IFC files, IFC files have problems such as missing information and errors during input and output [12–14]. Michael et al. proposed combining BIM and AR technology to make minor modifications to the existing information format (two-dimensional format). Applying AR technology to rapid response marking can significantly improve the information retrieval process and improve information retrieval speed, thereby increasing production efficiency [15].

The evaluation index of architectural design efficiency mainly includes two aspects, including the completion time of the architectural design task and the quality of the design task. It is very important to submit high-quality design works within a specified time and reduce design changes for the entire life cycle of a construction project. After inputting project-related information once, multiple users can quickly and reliably access such reliable data and improve design efficiency, which is BIM's most efficient and revolutionary function [2]. Therefore, a good 3D collaborative design platform based on BIM will effectively promote the improvement of architectural design efficiency.

3 Analysis of the Current Status of Collaborative Design

3.1 Collaborative Design Platform Application Status

Collaborative design refers to the design method in which the designer interacts with the design task in order to complete the same design task in the computer environment and finally obtains the design results that meet the design requirements. 3D collaborative design refers to the use of three-dimensional digital technology as the basis, three-dimensional design platform as the carrier, by different professional designers, including architecture, structure, equipment, machinery, electrical appliances, pipelines and other professions, to achieve common design goals and carry out collaborative design work, which is a process of data sharing and integration. In this process, designers use 3D models to share design information in the project process in real time and precisely. According to market research, the current common application in the field of architecture is collaborative design software based on secondary development of CAD work platforms, such as the Jinhui series of collaborative design products and Weiheng collaborative design platform. The collaborative design based on BIM software is less, mainly based on three-dimensional BIM software platform such as Revit, Bentley, and Tekla. Taking the collaborative design platform based on Revit as an example, it mainly achieves 3D collaborative design through two methods of working set mode and model linking. The working set mode is a collaborative design mode in which information is shared in real time. The members of the design team build the same building information model on the computers in the LAN. Each member designs in his own work set, and the design content is synchronized to the server of the project center in real time. Designers can borrow each other's model files or graphic elements to complete the cross design and achieve real-time sharing of information among members. In the working set mode, obtaining and releasing permission for modification is troublesome. It is applicable to architectural projects that can't be split and is often used in the same profession. It can not only reduce the pressure on the central folder and improve the working efficiency of the computer, but also can reduce the situation that other collaborators make wrong modifications to the model. Model linking is a collaborative design mode in which information is shared indirectly. It is usually used for model integration between different professions. It refers to the integration of models by importing external model links. The process is similar to the CAD import of external references, so that the information models among the professionals are visually shared. In this mode, the designer can't edit the linked model. The model occupies less computer space.

3.2 Analysis of the Reasons for the Less Application of 3D Collaborative Platform

Although 3D collaborative design has great advantages over 2D collaborative design, there are a few 3D collaborative design platforms based on BIM software. On the one hand, these platforms are not mature enough to be developed. They are generally limited to the visualization of BIM files and models, and do not support the customization of BIM sub-models by multiple parties. On the other hand, these platforms are limited to data sharing among multiple compatible software, and form an "information island" between software that is incompatible with the format. For example, the Revit collaborative design platform and the Tekla collaborative design platform can't effectively achieve data interoperability. This is mainly caused by the following two reasons.

(1) Incompatible Database Storage Format

In the process of architectural design, the software and platform used by designers are not unified, which describe the building information in different languages and use different data storage formats to store data. As a result, building information between various professions and platforms forms islands. At the same time, there are a lot of duplication of work, such as the reconstruction of the model, the re-entry of data and so on, when the work is transferred between professions or departments.

(2) Large Model Data

The data transmission of BIM software is usually based on the IFC standard. The IFC-complete sub-model focusing on one-time delivery is complex in analysis, high in calculation and space complexity, and low in transmission efficiency. It is difficult to support the collaborative work of high-density data interaction modes in multi-participants. In the process of 3D collaborative design based on BIM software, the entire model data is often used for sharing. However, for a specific stage of the project and the demand side, its requirements often involve only a certain part of BIM or related information composed of several parts. This leads to a large workload of software and poor data availability. In fact, in the process of collaborative design based on BIM, the requirements for relevant data are different according to the differences in architecture, structure, electromechanical and other professions. Therefore, there is a need to create interactive specific information for each design phase [16].

4 3D Collaborative Design P-BIM Cloud Platform Introduction

4.1 Related Theories of Building a 3D Collaborative Design Platform

In the process of implementing BIM's information interaction, three elements are mainly involved: people, software and standards. There are three main reasons why BIM can't completely realize data sharing. These are the incompleteness of BIM related standards, the immature development of BIM software on the market, and the lack of high-end BIM talents in the industry. This paper is mainly based on the first two considerations.

Table 1 Comparison of information exchange standards

Standard classification	Classification coding standard	Data model standard	Process exchange standard
IFC-BIM standard system	International Framework for Dictionaries	Industry Foundation Classes data model	Core Standard: Information Delivery Manual
			Derivative Standard: Model view definition
P-BIM standard system	Standard for classification and coding of building constructions design information model	"Unified Standard for the Application of Building Information Models"	General standard: "Architectural design P-BIM standard for software technology and information exchange"
			Substandard: "Deliver standard of building design information modeling";
			"Collection of standards for P-BIM software function and information exchange of building engineering"

(1) BIM Standard for Collaborative Design Platform

At present, the IFC standard compiled by buildingSMART has become the international mainstream BIM standard, providing a standard format for the information exchange of BIM application software in the construction industry, but its current level of completion is only about 5%. Therefore, in order to realize BIM in China as early as possible, with the support of the CBIMU, the industry has gradually started to compile the BIM standards, which were uniformly named the P-BIM series standards. The buildingSMART's purpose is to allow the sharing of information throughout the lifecycle of any built environment asset, between all the participants, regardless of which software application they are using [17]. The IFC-BIM standard system aims to establish a complete standard that makes this standard applicable to any situation where it may be necessary to exchange model data. The P-BIM standard is based on the characteristics of field engineering projects to conduct professional decomposition, and then establish a sub-model building information.

Data sharing usually requires three steps. Firstly, the information is classified. Secondly, the information storage format is specified. Finally, how to extract the data generated by the relevant participants is determined. Taking the standards required for data exchange in the design phase as an example, the P-BIM standard system and the IFC-BIM standard system are shown in Table 1. For classification coding standards, the P-BIM standard "Standard for classification and coding of building constructions design information model" is similar to the International Framework for Dictionaries standard. In terms of data model standards, the "Industry Foundation Classes data model standard" covers the entire life cycle of the BIM model. It defines the language of "express" to define data such as geometry, topology, geometric entities, personnel, costs, building components, building materials, etc. Therefore, based on the IFC-BIM standard, even a small amount of model data exchange needs to load a complete set of IFC classes, resulting in the IFC file taking up a lot of space whether it is in the plain text format of STEP or the ifcXML format. The "Unified Standard for the Application of Building Information Models" stipulates that the model structure system should be divided into task information model, common resource data, basic model elements and professional model elements. And for the interoperability of model data, it is better to use the "mdb" neutral file format [18]. In terms of process exchange standards, the "Collection of standards for P-BIM software function and information exchange of building engineering" formulates specific data exchange standards between professionals for the architectural design process. The IDM standard is too large compared to the "Collection of standards for P-BIM software function and information exchange of building engineering". The "Collection of standards for P-BIM software function and information exchange of building engineering" stipulates requirements of data exchange and delivery standards among related software in the architectural design process, including the foundation pit design, foundation design, concrete structure design, steel structure design, masonry structure design, water supply and drainage design, heating ventilation and air conditioning design, electrical design, green building design evaluation and professional P-BIM software, etc. [19]. The case of this paper is mainly based on the data transfer of architectural design sub-model to concrete structure design and HVAC design, as shown in Sect. 5. Therefore, the "Standard for P-BIM software function and information exchange of concrete structural design" and

"Standard for P-BIM software function and information exchange of heating ventilation and air conditioning design" are mainly introduced here. The "Standard for P-BIM software function and information exchange of concrete structural design" stipulates the geometry data that the architectural design sub-model should introduce into the concrete structure data sheet, including the total height of the building, the number of floors, the number of floors above the ground, the height of the outdoor ground, the elevation of the ground floor, the height of each floor, the direction of the north needle, the information of the plane grid, the size of the building control, the location of the main components, etc. [20]. The "Standard for P-BIM software function and information exchange of heating ventilation and air conditioning design" specifies that the geometric information imported from the architectural design sub-model should include the total height of the building, the number of floors, the number of floors above the ground, the height of the outdoor ground, the elevation of the ground floor, the height of each floor, the direction of the north arrow, the size of the building control, and the location of the main components, etc. [21].

(2) Collaborative Design Software

Firstly, from the perspective of information exchange, IFC-BIM aims at central integration, and all professionals exchange data with one central model. P-BIM uses a decentralized data integration approach, where each profession has its own model data and only needs to exchange data with personnel who need to exchange data. This "on-demand delivery" greatly reduces the data capacity transferred between software and solves the problem of data redundancy for data exchange in accordance with the IFC-BIM standard. Secondly, from the level of collaborative design software, software can interact with data for compatible formats In IFC-BIM mode. The P-BIM standard's "on-demand delivery" and delivery in the "mdb" neutral data format make this standard suitable for any software on the market.

4.2 The Composition of P-BIM Cloud Platform

Based on the above theories, the secondary development of the software at the Shenzhen University BIM laboratory was carried out according to the "Collection of standards for P-BIM software function and information exchange of building engineering", and a P-BIM cloud platform that meets the standards was developed. It is used for collaborative design of surveys, foundation pits, foundations, buildings, structures, water supply and drainage, heating and ventilation, and electrical engineering. The P-BIM Cloud Platform includes P-BIM Cloud, a series of P-BIM architectural design software, and user's clients corresponding to architectural design software. The user's client is called a P-BIM client to enable users to upload or receive model data. P-BIM architectural design software refers to adding P-BIM plug-ins to the original design software to export or read model data. The P-BIM cloud refers to the virtual storage delivery data platform.

4.3 Characteristics of Information Exchange Based on P-BIM Cloud Platform

According to the above analysis, the process of information exchange based on the P-BIM cloud platform mainly has the following three characteristics.

(1) Designers Do not Need to Change Their Work Habits
Collaborative design based on the P-BIM cloud platform allows designers to follow their original design habits and use their own familiar design software without having to learn related BIM software in order to interact with model data. This will save designers a lot of time to learn BIM and improve the performance of the entire industry.

(2) Lightweight Data transfer
The P-BIM standard subdivides the data requirements of the data exchange participants according to the characteristics of the field project, and formulates standards for information interaction among professionals. Therefore, software that is debugged according to "Collection of standards for P-BIM software function and information exchange of building engineering", can reduce the transfer of redundant data and achieve lightweight transmission when information is exchanged. While reducing the requirements for computer software and hardware in the collaborative work process, it can also save the receiver's processing of data.

(3) Unified Model Information Exchange Format
With the IFC-BIM data exchange method, it is necessary to unify the conceptual model of the database. That is, software vendors need to make major changes to the software format. The P-BIM data exchange method only requires the use of plug-ins to change the external mode of the database, and the format of the transmitted data is unified to the mdb. This format has the characteristics of small capacity and easy readability, which reduces the difficulty of software developers.

5 Case Study

5.1 Experiment Procedure

This paper takes a dormitory building of Shenzhen University as a case to conduct model data interaction experiment based on P-BIM cloud platform. The P-BIM cloud platform used includes P-BIM clients and P-BIM software for architecture design, structure design and HVAC design. This paper describes the process of information exchange between architectural design, structural design and HVAC design, based on the P-BIM cloud platform. Since the data transfer mode is similar, this paper focuses on architecture design transfer model information to the structure design and HVAC design. The experimental process is mainly divided into three steps. Firstly, the architectural design professional uploads the model data. Secondly, the structural design professional receives the model data. Finally, the HVAC professional receives the model data. The interaction process is shown in Fig. 1.

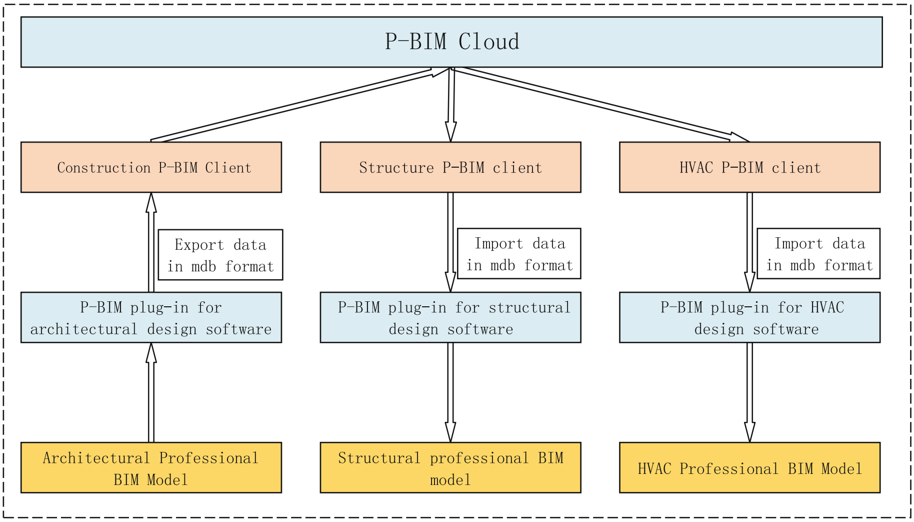

Fig. 1. Data interaction process

(1) Uploading Model Data by Architectural Design

This case uses ArchiCAD software for architectural modeling. The building model is shown in Fig. 2. The model can export 9 data files through the P-BIM plug-in, and the files are named according to the "Standard for classification and coding of building constructions design information model". Firstly, the architectural designer uses the architectural design P-BIM software to export the architectural design BIM model to a file with the format "mdb". Then the architectural designer logs into the architectural design P-BIM client and upload the exported data file to the P-BIM client. The uploading process is as shown in Fig. 3. After the upload is complete, the system automatically prompts the upload of the file, as shown in Fig. 4.

(2) Receiving Model Data by Structural Design

This case uses PKPM software as the P-BIM structure design software for the P-BIM cloud platform. Firstly, the structural designer logs in to the structural design P-BIM client, and the system will automatically remind "new tasks to be processed", as shown in Fig. 5. After clicking "Yes", the structural designer selects the file named

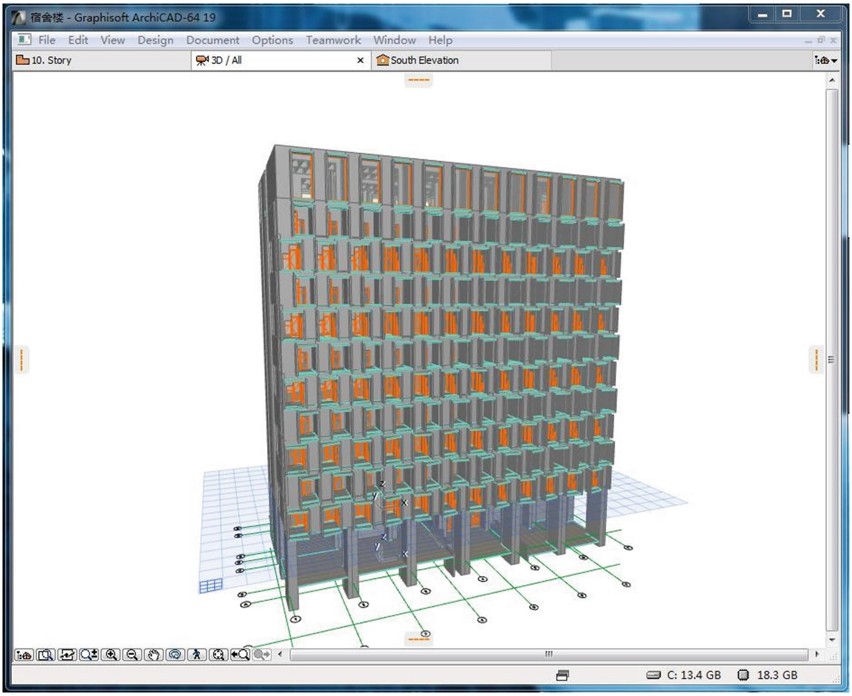

Fig. 2. BIM model of architectural design

"Architectural design to concrete structure design" to download. Secondly, the structural designer uses PKPM software to open the downloaded data file, and the software will automatically read the data to generate the model needed for structural design, as shown in Fig. 6.

(3) Receiving Model Data by HVAC Design

This case uses Hongye Software as HVAC design P-BIM software for the P-BIM cloud platform. Similar to the structural design, firstly, the HVAC designer logs in HVAC design P-BIM client and the system will automatically remind "new tasks to be processed", then clicks "Yes" to generate the interface, as shown in Fig. 7. Secondly, the

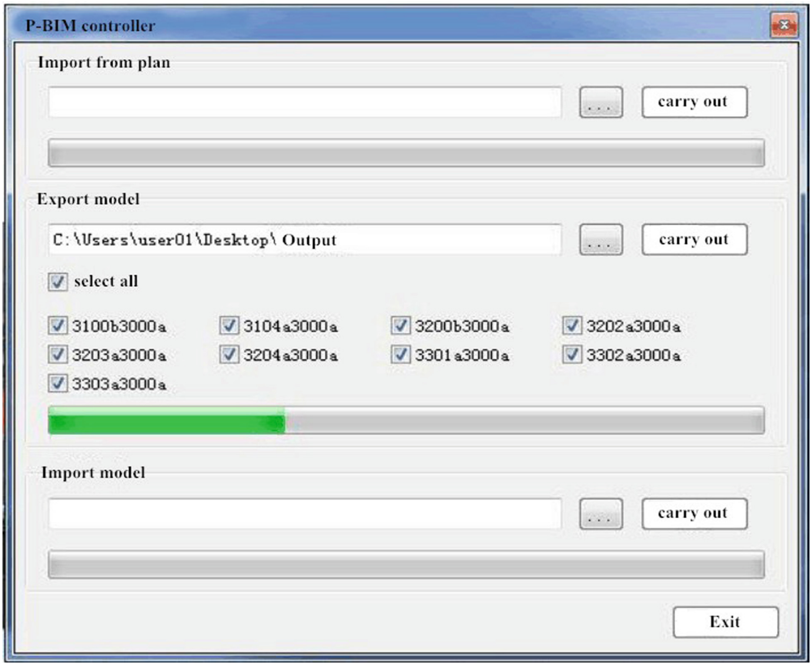

Fig. 3. Upload process diagram

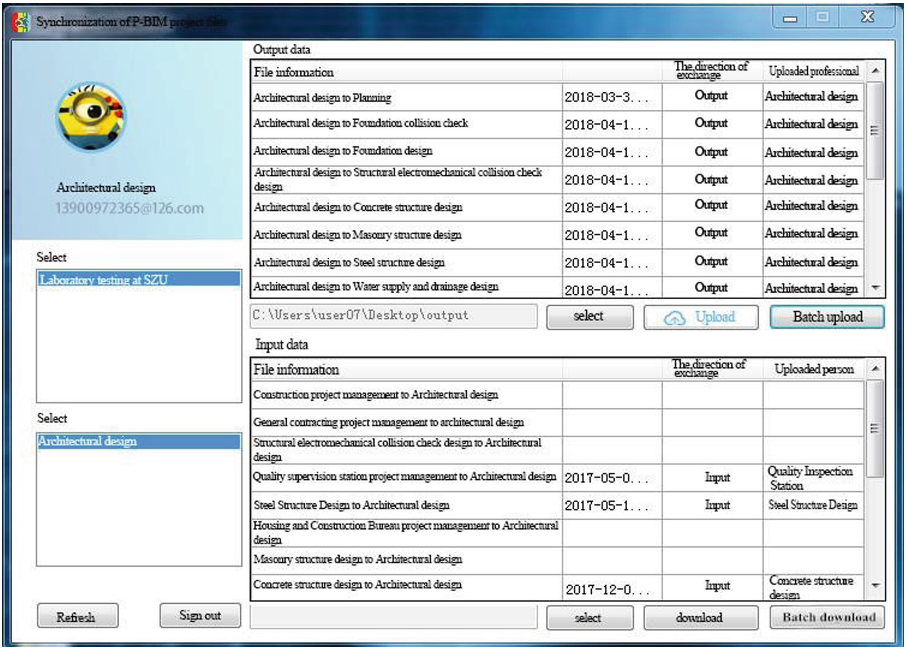

Fig. 4. Architectural design P-BIM Client

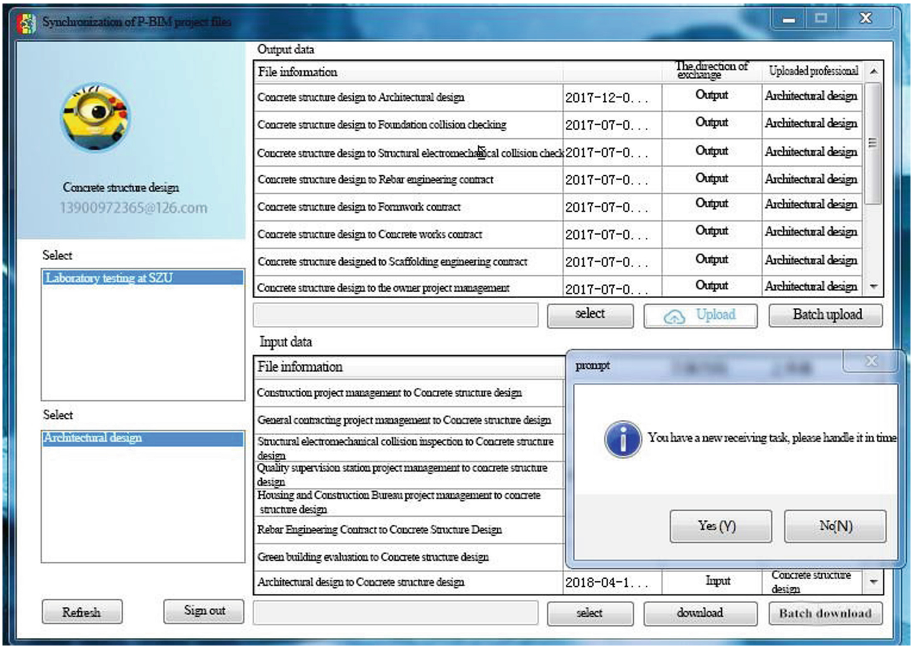

Fig. 5. Structural design P-BIM Client

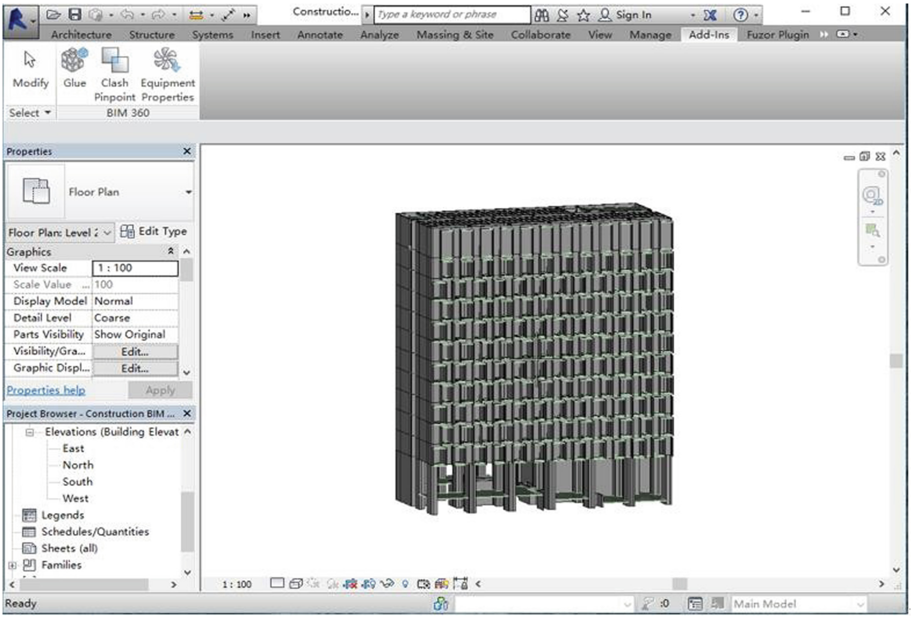

Fig. 6. BIM model of structure design

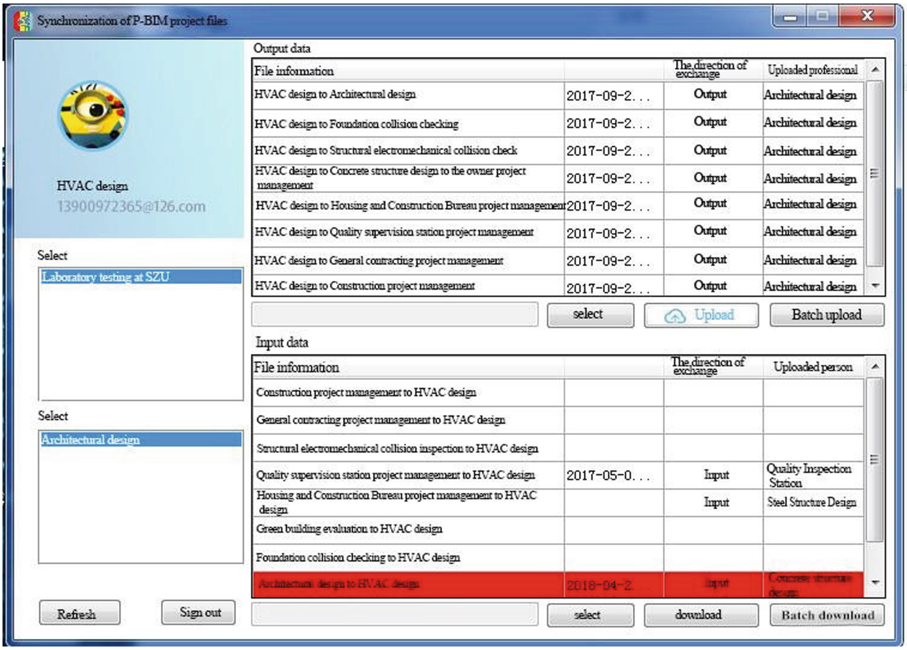

Fig. 7. HVAC design P-BIM client

HVAC designer selects the file named "Architectural design to HVAC Design" for download, then uses the Hongye design software that has the P-BIM plug-in installed to open the data file. The software will automatically read the data and generate a BIM model, as shown in Fig. 8.

5.2 Results and Discussions

According to the experimental results, based on the P-BIM cloud platform, information transmission of BIM model data can be effectively implemented. Considering the structural design and the HVAC design, the structural designer can design based on the models passed by other parties, reducing the time for the secondary modeling. The HVAC designers can design based on models passed by other parties, reducing the collisions caused by the HVAC design and reducing the modification time after the collection of design results for each major. Therefore, it is concluded that the collaborative design based on the P-BIM cloud platform can achieve the purpose of improving the design efficiency. This method can not only make the model data lightweight and reduce the requirements for computer hardware, but also solve the "information island" of software and reduce the repetitive work of the data demand side.

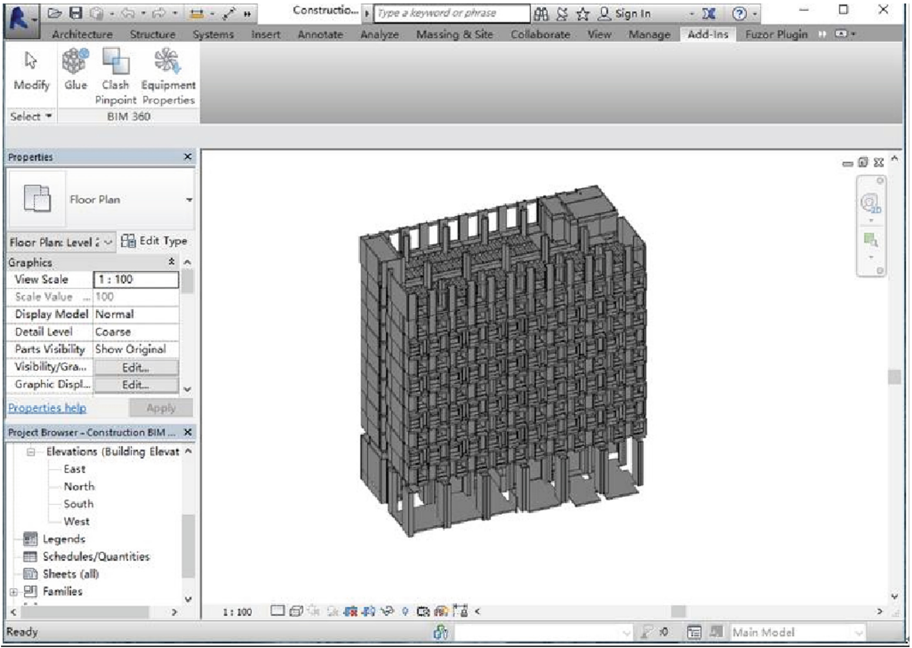

Fig. 8. BIM model of HVAC design

6 Conclusions

This study analyzes the current application status of collaborative design platforms in the field of architectural design in China, and concludes that the application of BIM in collaborative design mainly has the problem that information can't be effectively interacted. At present, there exists a problem of data redundancy when the international mainstream IFC-BIM implements data sharing. Therefore, a collaborative design method based on the P-BIM cloud platform is proposed. This paper expounds the foundation of the P-BIM cloud platform from the theoretical aspect, and through experiment, implements the lightweight data transmission from P-BIM architectural design software to structure design P-BIM software and HVAC design P-BIM software. The experimental results show that collaborative design based on P-BIM cloud platform can quickly transfer data according to the specific needs of data demanders, and then effectively improve design efficiency.

The further development of BIM at the application level of software requires the active promotion of relevant stakeholders such as software vendors, governments, design institutes, owners and other relevant stakeholders. At the same time, we need to consider the three key elements of BIM, namely people, software, and standards. Therefore, on the one hand, the curriculum education of universities in BIM needs to be strengthen, so that universities can train more talents in BIM. On the other hand, while guiding the industry in formulating BIM standards, the government should also promote software vendors to actively improve software according to standards.

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