COLLABORATIVE DESIGN SYSTEM FOR CONSTRUCTION PROJECTS BASED ON CLOUD-BIM

Jie Chen, Master Candidate, chenjiesmile07@hotmail.com
Department of Construction Management, Tsinghua University, Beijing, China

Diankun Wu,Engineer,59265909@qq.com
CCCC Second Highway Consultant Co. Ltd., Wuhan, China

Hongling Guo, Associate Professor, hlguo@tsinghua.edu.cn
Department of Construction Management, Tsinghua University, Beijing, China

Jun Li, Engineer, 59265909@qq.com
China Railway SIYUAN Survey & Design Group Co., Ltd., Wuhan, China

ABSTRACT

The design of construction projects involves different disciplines, e.g. architectural, structural, and MEP (Mechanical, Electrical and Plumping). These disciplines are often carried out separately by different designers, and as a result design conflicts or problems occur in construction sites. Collaborative design is regarded as an effective approach to remove design problems. Aiming at the requirements of collaborative design for construction projects, the integration of Cloud and BIM into collaborative design is regarded as a promising approach to improve the performance of collaborative design. This research proposes the conceptual framework of a collaborative design system based on Cloud-BIM and analyzes its main functions, including BIM modeling, task division and collaborative design, designers' authority management, conflict detection and resolution, knowledge management, and the analysis of extended functionality based on the BIM model. The general implementation process of the collaborative design system is also presented. In the end, a real-life case is adopted to demonstrate the implementation of this system. It is shown that the system proposed has a potential to support the collaborative design of construction projects.

Keywords: construction projects; collaborative design; cloud computing; BIM

1. INTRODUCTION

The design of construction projects involves different disciplines such architecture, structure and mechanical/electrical/plumping (MEP), which are usually implemented separately by different parties, e.g. architects, structural engineers and BS engineers in the construction industry. When all disciplines of drawings are assembled on site, lots of problems often occur, for example design conflicts among different disciplines. These problems lead to cost and time overrun, high accident rate, etc. This is also one of the most important reasons for the low productivity of the construction industry worldwide. In order to overcome the fragmentation of design of construction projects, some research has been conducted in recent years. Collaborative design is regarded as a promising approach to improve the communication and collaboration among different design parties.

Collaborative design refers to that different design parties carry on the design of construction projects with each other on a same platform. The aim of collaborative design is to solve design problems caused by different design disciplines in time or rapidly in the design stage. According to whether different design parties do design work at the same time or not, the collaborative design can be divided into the asynchronous collaborative design and the synchronous collaborative design. For design work in different locations or not, the collaborative design can be divided into the distributed collaborative design and the co-located collaborative design. The distributed synchronous collaborative design is a kind of emerging design approach in recent years. This design approach allows the AEC engineers and other stakeholders in different locations to design the construction project together through the network by using a variety of different computer aided design tools. In the whole design process, each designer can feel the presence of other designers and communicate with each other. The distributed synchronous collaborative design can guarantee that the designers can carry on the design work in different locations at the same time. Also it can reduce or even eliminate the impact of the communication barriers to the design work as far as possible. However, the concept of collaboration design is not implemented well in the construction industry. One of the most important reasons is that existing collaborative design tools cannot efficiently support collaborative design among different parties.

The rapid development of information technology, such as cloud computing technology and BIM (Building Information Modeling) technology, makes collaborative design possible. Particularly the combination of BIM and cloud computing technology, i.e. Cloud-BIM, extends their contributions to collaboration design. That is, BIM software packages, BIM computing, and BIM data storage are integrated with Cloud Servers, based on which Cloud-BIM model creation, model display, clash detection, animation, construction simulation and other functions are integrated and implemented. Whether how large the model of a construction project is or how complicated it is, it does not require the high performance of local computers because the requirements of computing power can be met by the cloud server. Besides, software is also provided and updated by the Could-BIM service provider, which makes cost low. This research makes an effort to apply Cloud-BIM to support the collaborative design of construction projects. The conceptual framework of a Could-BIM-based collaborative design system is proposed and its implementation process presented in the following sections. In the end, a case study is employed to demonstrate the feasibility and validity of this collaborative design system.

2. CONCEPTUAL FRAMEWORK OF THE CLOUD-BIM-BASED COLLABORATIVE DESIGN SYSTEM

The Cloud-BIM-based collaborative design system for construction projects refers to a platform that integrates BIM data (drawings and 3D models), BIM modeling software packages, BIM analysis software packages, etc. in a Cloud Server, and allows different designers to access the Cloud Server and use these software packages and data for collaborative design at the same time. The main functions of the collaborative design system include BIM modeling, task division and collaborative design, designers' authority management, conflict detection and resolution, knowledge management, and the analysis of extended functionality based on the BIM model. The conceptual framework of the collaborative design system and basic module are shown in Figure 1.

2.1 BIM modeling module

The implementation of the collaborative design system is based on the 3D BIM model of a construction project which is stored in a Cloud Server. The 3D model involves various component models, for example, architectural components, structural components, MEP components, etc. The BIM modeling module provides different designers for the establishment of BIM models of different disciplines within the same platform. These models are built and arranged based on relevant properties and rules, that is, the properties of component models include component category, appearance, material etc., while the rules refer to the connection rules, such as intersection and disjoint, which is also regarded as a kind of shared attributes with other component models. In the intersection case, an intersecting part is identified by Boolean operation; while in the disjoint case, there is no direct relationship between two components, both can be completely independent in the modeling process.

2.2 Design task division and collaborative design module

Task division is the precondition of collaborative design and may facilitate the assignment of tasks. The design tasks of construction projects can be divided into three main fields: architecture, structure and MEP. There are secondary fields, such as HVAC, water supply and drainage and electrical in the MEP field. For each field or subfield, the design tasks may be divided based on the space area and workload, meanwhile, based on the time sequence.

The principles of task division are summarized as follows:

- According to the division of fields (three fields known as architecture, structure, and equipment);
- According to the division of space area;
- According to the temperature joint, the seismic joint and the settlement joint;
- According to the construction phase partitioning.

According to the spatial relationship of components within a design task the component primitives can be divided into two categories: internal primitives and fringe primitives. An internal primitive only has the attributes of intersection within the design task, and has no connection with primitives in other design tasks. A fringe primitive has connection with one primitive or more in other design tasks. Different task partitions contact each other by fringe primitives.

When each designer conducts his/her own design tasks, he/she can create or modify relevant internal primitives by him / herself. But for fringe primitives, he/she has to collaborate with other designers. After he/she creates the internal attributes of a fringe primitive, other relevant designers could add its connection attributes.

For design collaboration within a same discipline, it aims to solve design problems within fringe primitives, including primitives' repetition, omission or error. This requires an efficient and effective coordination and communication with designers. What's more, design problems should be checked again after one design task is completed. On the other hand, for design collaboration among different disciplines, the aim is to find and solve the spatial conflict among primitives, which can be checked by using the function of conflict detection embedded in BIM software.

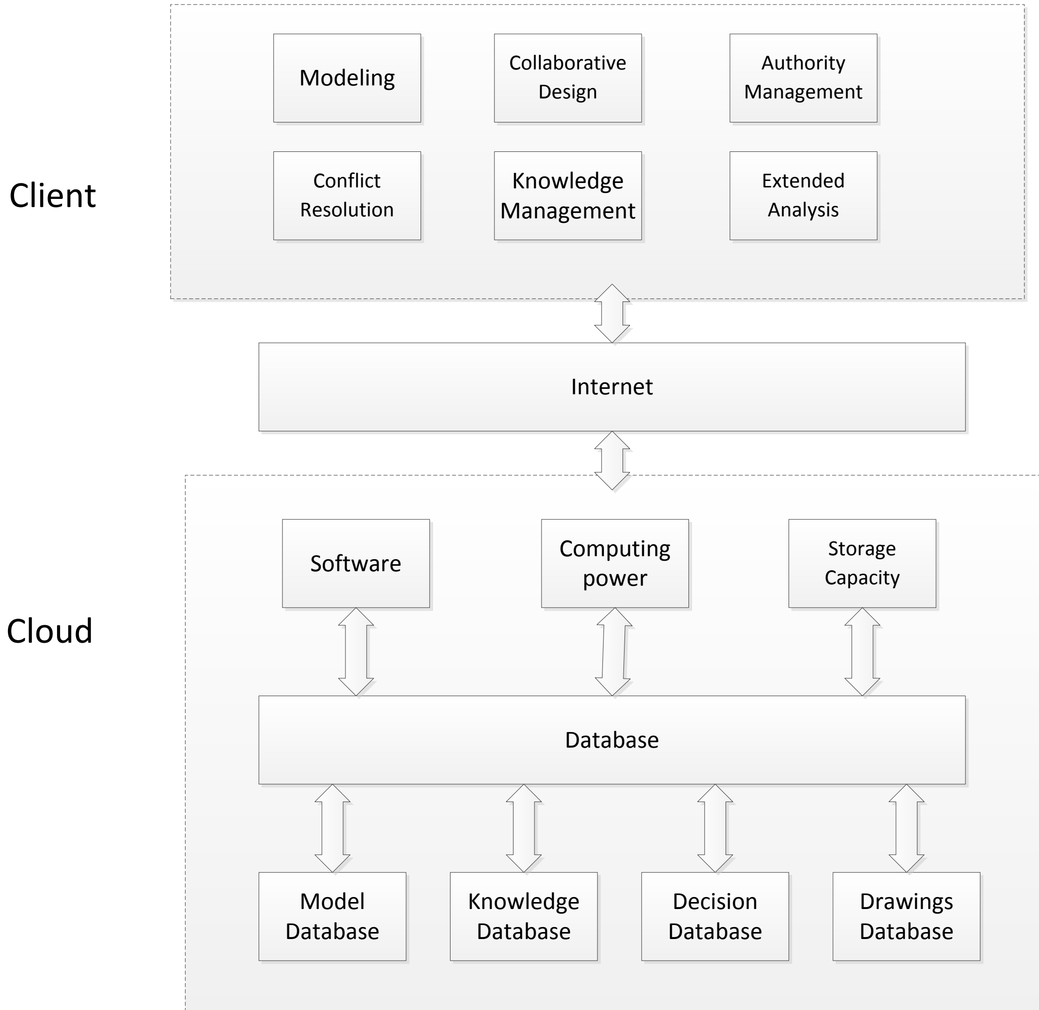

Figure 1: The conceptual framework of the Cloud-BIM-based collaborative design system

2.3 Designers' authority management module

The designers' authority module includes the permissions to create and modify primitives in a design task partition, the permissions to modify primitives from other relevant design task partitions, and the permissions to browse overall BIM models. In the collaborative design system based on Cloud-BIM, participants need to access relevant cloud data. But, each participant has different status, professional field, tasks division; What's more, different data has different shared scope, cooperative awareness needs and security requirements. All of these need to make an access control strategy. Or it would lead to many problems, such as access error, conflict and unauthorized access, etc. Therefore, there is great significance to the security of the system resources by customizing permissions management mechanism. As design progress goes on, relevant designers' authority is also changing. A good designers' authority management mechanism can ensure a clear division of responsibilities, which contributes to the efficient and high-quality completion of design tasks.

2.4 Conflict detection and resolution module

To remove conflicts is one of the core problems solved by the collaborative design system. The conflict detection and resolution process of a distributed collaborative design system involves conflict detection, communication and resolution, which assists designers in achieving a reasonable and optimized design scheme.

In the collaborative design system, each of design objects - primitives has its own design variables which always connect with each other tightly. The relationship of different design variables constitutes a constraint. Normally, conflicts are caused by the violation of constraints. Conflict detection is mainly based on relevant constraints. The system detects and captures conflicts on the basis of the 3D model and records them. After real-time detecting some conflicts, it registers and refreshes these conflicts in the library. It can also removes the conflicts resolved from the library, to ensure that the records of current conflicts in the library are effective. On the other hand, the most common type of conflict is spatial collision among, through detection software in the cloud server, such kind of conflicts can be quickly found in the BIM model. Then these conflicts can be delivered to relevant designers by conflict reports (see Figure 2). Through the communication and coordination among the designers, the conflicts can be quickly resolved.

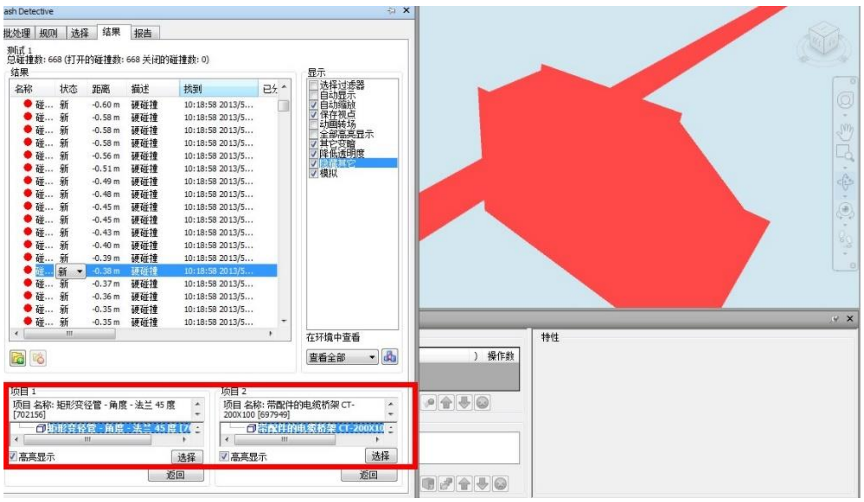

Figure 1: A conflict report

2.5 Knowledge management module

During the collaborative design process of construction projects, it would produce a large number of 3D models, drawings, documentation, etc., for example, conflict reports , conflict resolution reports, as well as difficulties and relevant solutions, which can be stored as knowledge for future projects. So the knowledge management module is an important component of the collaborative design system. It involves model management, the records of the working progress, the conflict reports and the conflict resolution reports, and design results management.

2.6 BIM-based extended analysis module

The analysis of extended functionality, such as structural analysis, energy consumption analysis, and illumination analysis and so on, can be carried out easily by using relevant software packages integrated in the cloud server, based on the same BIM model. Figure 3 shows the structural analysis of a project design using the proposed system. Each functional software provides an operation interface related to the BIM database, and this makes extended analysis possible based on the cloud-BIM model. The system also makes it possible to transfer relevant BIM models from one format to another format to meet the requirements of different software.

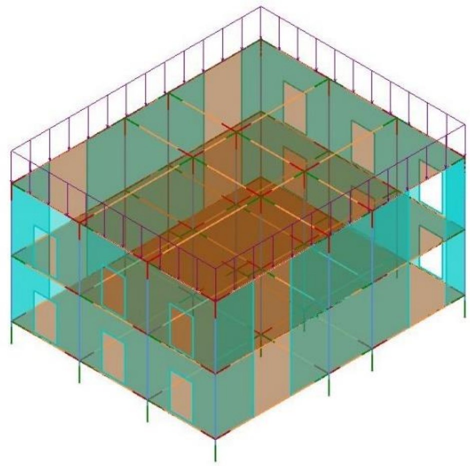

Figure 2: Structural analysis based on the Cloud-BIM-based collaborative design system

3. IMPLEMENTATION OF THE CLOUD-BIM-BASED COLLABORATIVE DESIGN SYSTEM

The proposed Cloud-BIM-based collaborative design system is fully erected in a cloud server. Its computing power and storage capacity is provided by the cloud server, such as the software related to design, functional analysis, communication, and so on. The design process and options are also stored in the cloud server. All stakeholders can conveniently check in or out a project design in the cloud server through network. The implementation process of the Cloud-BIM-based collaborative design system is presented as follows.

3.1 The general work process

The whole design process of a construction project can be completed in the collaborative design system. The main work process may be divided into mission planning, preliminary design (including task division and collaborative design), model merging, conflict detection and adjustment, detailed design (including task division and collaborative design), final modeling, and drawings (see Figure 4).

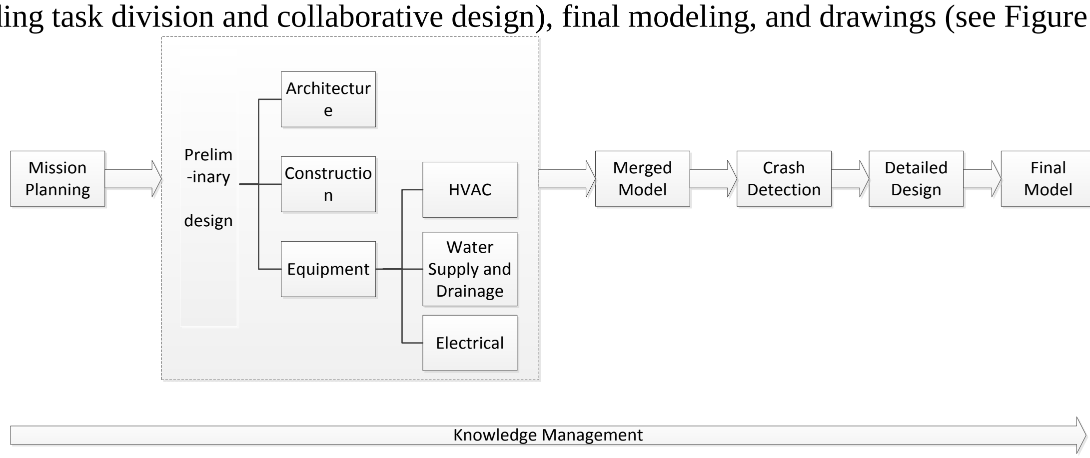

Figure 3: The general work process of the Cloud-BIM-based collaborative design system

3.2 Mission planning

The mission planning of design of construction projects is the beginning of the whole design process, also the underpinning of other design activities. Mission planning includes design goals, design tasks, design scheduling, etc. For the Cloud-BIM-based collaborative design system, design goals are to achieve not only project functions, but also 3D modeling accuracy. According to the design goals, design tasks can be carried out in accordance with general rules.

3.3 Interoperation of 3D models

The interoperation of 3D models refers to that designers need to manipulate (view or modify, delete, etc.) models or primitives outside their own task partitions during the process of collaborative design. In the Cloud-BIM-based collaborative design system, all model data are stored in the same database. Designers can check and operate models, which may be regarded as references for their own design, by configuring their display areas or fileters at any time.

The designers have two ways to operate (modify or delete) the primitives outside their own task partitions.

(1)Apply for the operating permissions of primitives from the system. Once such permissions are approved, the system suspends the original designers' permissions to operate relevant primitives at the same time. When operations are finished, the system releases the permissions and sends messages related to relevant operations to the original designers. If the original designers do not agree with the operations, they may be ignored. At the same time, aiming at relevant design modification, all relevant designers can request for mediation.

(2)Send messages to the original designers and state operation contents and reasons. The original designers may modify, delete, or just rejected these suggestions.

4. CASE STUDY

Loukouni bridge is a large-span steel-box bridge, located on Congo National Road No. 1, crossing Loukouni River. With the total length of 161.22 m, the bridge includes a main span with a bearing steel-box arch and group pile foundation, approaches with reinforced concrete rectangular beams, column piers, and pillar abutments. BIM approach has been adopted to aid in the design and construction of this bridge project. The 3D model of this bridge was built as shown in Figure 5 based on the drawings of preliminary design. It is employed to demonstrate the implementation of the Cloud-BIM-based collaborative design system.

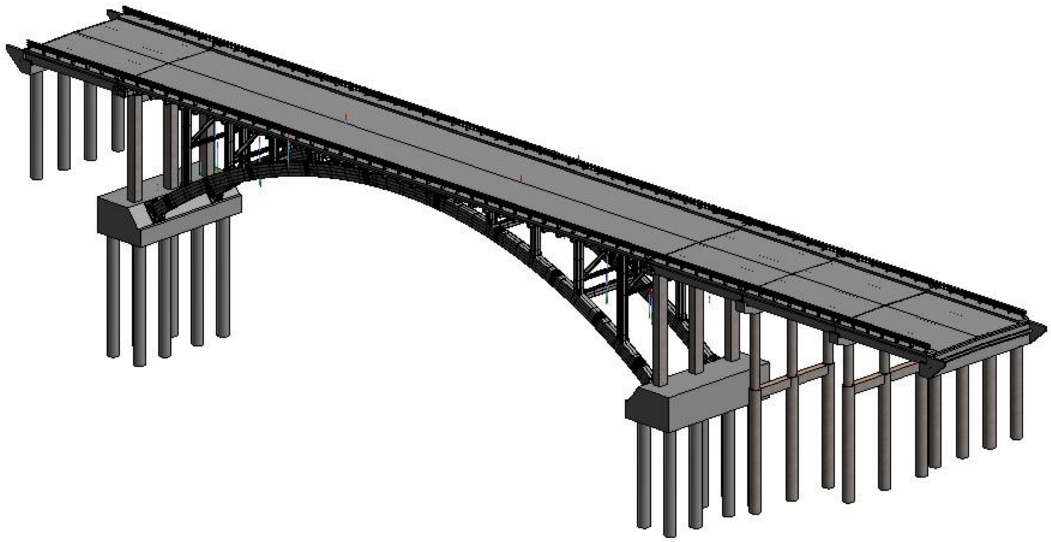

Figure 4 3D model of Loukouni bridge

The model of Loukouni bridge was mainly based on the drawings of preliminary design. In the mission planning stage, the modeling accuracy of Loukouni bridge was configured to LOD 400. The whole model was mainly divided into the following parts:

(1)Steel structures, including arches, spandrel columns, steel box beams and relevant fittings;

(2)Concrete structures, including abutments, skewbacks, approaches and pile foundation; and

(3)Decorative parts, including bridge deck, railing, etc.

In the stage of 3D modeling, it involved many operating interfaces for the interoperation of the 3D models, for example that between arches and skewbacks (see Figure 6). According to the task partitions, arch and skewback belong to two different designers. But both of them are closely linked, especially in their spatial location relationship and their connector assembly, which needs coordination and collaboration among different designers.

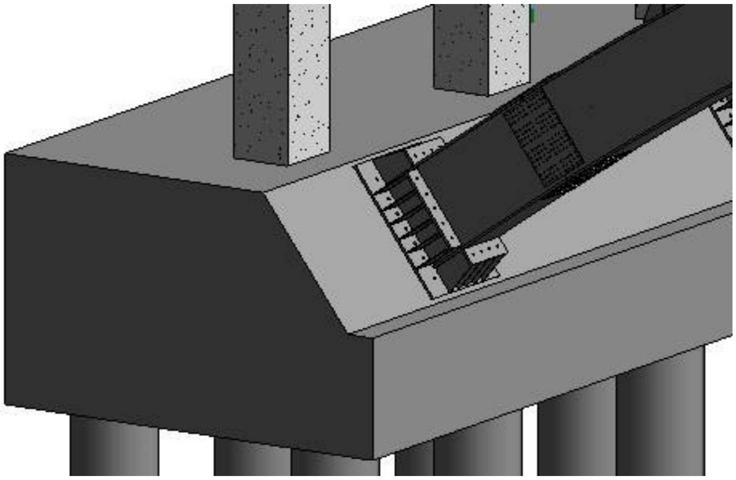

Figure 5: An arch and a skewback

In this case, the collaborative design focused on the solution of design conflicts. On the basis of the existing 3D models built in this case, design conflicts among different bridge components are detected by using the Cloud-BIM-based collaborative design system. Different designers participated in the process of collaborative design. This succeeded in eliminating relevant conflicts in the design of this bridge. By interviewing with relevant designers, it was founded that this made the design of bridge more constructable than before and also improved the effectiveness and efficiency of collaborative design. Although this system is only used as a trial in this case, it is shown that it has potential to support the collaborative design of construction projects.

5. CONCLUSIONS

In order to meet the requirements of collaborative design for construction projects and improve the performance of collaborative design, this research integrates Cloud-BIM into collaborative design. The conceptual framework of a collaborative design system based on Cloud-BIM is proposed, including its main functions, i.e. BIM modeling, task division and collaborative design, designers' authority management, conflict detection and resolution, knowledge management, and the analysis of extended functionality based on the BIM model. Its general implementation process is also presented and tested by using a real-life case. It is shown that the system proposed has a potential to support the collaborative design of construction projects and improve its performance.

This collaborative design system has a great integration of the functional requirements of different stakeholders. The information of BIM model is taken full advantage of, to avoid repeatedly modeling and make design work efficient. However, this system is not yet completely tested in real cases. Thus the future research should focus on the verification of validity of this system. Otherwise, the interoperation of 3D models also needs to be further studied.

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