MULTI-DISCIPLINARY DESIGN COLLABORATION FOR DEVELOPING A BIM MODEL USING A HYBRID CLIENT-SERVER AND P2P NETWORK MODEL

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ABSTRACT: This paper presents an Internet-based design collaboration of multi-disciplinary teams for the development of a Building Information Modeling (BIM) model. The network allows geographically separated design teams to work simultaneously on a single shared BIM model, using a distributed system to achieve design integration and conflict resolution. A synchronous collaborative design platform for inter-disciplinary collaboration was developed in this study. By using the proposed platform, the members of various design teams can be connected via the Internet to work in the same virtual design space, where they can see the progress of other teams' work and cooperate in real-time. All design data is centrally maintained in a database to provide secure and systematic data management. A hybrid Client-Server and Peer-to-Peer (P2P) network model was proposed for such design collaboration. The network has two levels. Inter-disciplinary teams are linked in a Client-Server network; within intra-disciplinary members, individual team members are linked in a P2P network. This network model allows for efficient multi-disciplinary collaboration in the development of BIM models. Stable operating mechanisms and suitable access rules are imposed to maintain the integrity of the system.

Keywords: *Internet, BIM Model, Collaboration, Multi-discipline, Computer-aided Design*

1. INTRODUCTION

The construction industry has the characteristics of product specialization, customization and the need for inter-disciplinary teamwork. Each construction project requires building its own unique model using the Computer-Aided Design (CAD) program, which is a time-consuming and labor-intensive job, and requires teamwork and collaboration. People from different disciplines build engage in inter-disciplinary collaboration through which they integrate the specialized and common design parameters from each other. With the growing need to advance the development of the construction industry information system and to efficiently manage the construction model building, Building Information Model (BIM), a model to describe a construction model, is developed. BIM relates actual building components to the CAD model. The model therefore not only contains 2D and 3D graphics parameters, but also has the design attributes related to different fields and stages of the construction project [1]. Due to these advanced features, the development of a BIM model requires multi-disciplinary teams to cooperate on integrating their designs.

Different stages of the construction project (A/E/C, Architecture/Engineering/Construction) all require the participation and collaboration of specialists from different areas. Therefore, it is important for the team members to communicate and share the information while customizing the BIM model. Currently, however, the common BIM collaborative design model for inter-disciplinary collaboration is achieved by exchange and combination of the design files. When building the BIM model for every particular discipline, teams from different disciplines work individually at separate geographic locations and use various specialized software. Therefore, for a single construction project, there exists various BIM models from different disciplines, and all these different BIM models need to be combined into a single BIM model. Thus, the integration of BIM models is asynchronous [2]. During the inter-disciplinary collaboration process, numerous design parameters need to be set. Most of the parameters need to be discussed and determined by more than one team. When combining the individual BIM models into a single BIM model on relevant software platforms, the design parameters of different disciplines are likely to conflict with each other. Due to dependency between a number of design parameters and the lack of information on each team's design progress and details, resolving the conflicting parameters consumes a large amount of time and human resources.

In recent years, with the continuous development of Internet-related technology and the increase of network bandwidth, the distributed network system now can economically provide support to long-distance real-time operations. This revolutionarily transforms the modes of organizational communication, resource exchange and corporate collaboration. Some researchers have utilized web-related technologies in CAD to allow real-time synchronous collaboration between users over the web [3]. With regards to the above-mentioned problem in integrating the individual BIM models from different disciplines, since the Internet is an ideal medium to support distributed teamwork for communication and exchange of design data.

The goal of this study is to leverage on Internet technology to create a collaborative design environment which allows all connected teams to work together in the same virtual space, integrating their discipline-specific designs into a single BIM model. In this environment, each online user can add their individual contributions to the model, and also view the progress of one another's work in real-time. The workflow of multi-disciplinary design collaboration in construction projects is shown in Figure 1. Only one team works on the design at a time and each team has a group of members to share the work and cooperate concurrently. When one team completes their design, the design is then transferred to the next team for further design work. If any change in design is required, the design will be returned to the previous team for adjustment.

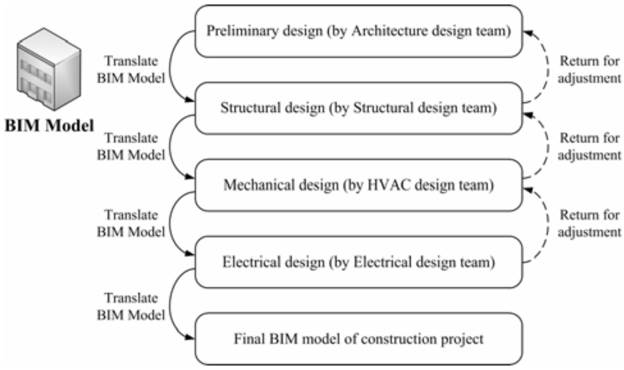

Fig. 1 Construction Project - BIM Model Building Procedure.

Therefore, the proposed Internet-based mode and technology must support this design process. It should not simply allow the BIM model to be transferred among teams online, but also allow the members of each team to cooperate concurrently in an Internet-connected environment. For such a distributed system, a network model would be a basic requirement. There are two major types of communication network models, one is the Client-Server network, and the other is the Peer-to-Peer (P2P) network. The Client-Server network is the most basic connection model to connect the global server with each client. In this model, the server is acting as the bridge for data transmission between each client. On the other hand, the main feature of the P2P model is that it consists of the peers acting as both the server and the client. Therefore, all the peers have the capability to communicate with each other directly. The advantages of the Client-Server network model are that they are more secure and information is managed more easily, not requiring unnecessary duplication of information, whereas the advantages of the P2P network model are that they enable more efficient communication, are more crash-proof, and take advantage of idle computing capacity. In this environment, each online user can not only add their contribution to the model in sequence, but also view the progress of others' work in real-time.

The BIM model has two types of collaborations, which are inter-disciplinary collaboration and intra-disciplinary collaboration. The inter-disciplinary collaboration is asynchronous. Apart from the primary discussion about the design plan at the initial stage, the collaboration model is that each team will not pass on its design to other teams until all the designs or modifications from its responsibilities are completed. Therefore, achieving effective exchange among the teams and maintaining the consistency of information becomes the main aim of the collaboration. The Client-Server network structure provides a global database and enables each team to exchange and manage the data via the Internet. This is considered to be the optimal model, when considering data maintenance and management efforts. The intra-disciplinary collaboration is synchronous. The common collaboration model is to assign the design tasks to the various team members and work simultaneously. During the collaboration, the team members need to communicate frequently to view the progress as a whole. This process enables the integration of designs from various members. Hence, the main aim of the collaboration is to maintain the information transmission efficiency, the average workload of the distributed process, the system fault-tolerance level and convenience in connecting each member. Considering the stability, autonomy, extensibility and convenience of the system, the optimal choice is the P2P model. The traditional Client-Server network and the emerging P2P model can support both of the above-mentioned collaboration models. This study focuses on the characteristics and operational model of the construction project's inter-disciplinary and intra-disciplinary collaboration, and proposes a hybrid Client-Server and P2P network model.

2. OBJECTIVE

Considering the inter-disciplinary design attributes and parameters in the BIM model, and the collaborative operation model, the objective of this paper is to study the hybrid Client-Server and P2P network model. The current unitary network infrastructure can only satisfy the need of a single type of construction project collaboration. A hybrid network infrastructure can better meet the requirements of the inter-disciplinary collaboration of a construction project and provide effective communication modes between members from different disciplines. In this way, real-time collaboration of inter-disciplinary and intra-disciplinary teams can be achieved, and the efficiency of the BIM model collaboration, improved. The network model is illustrated in Figure 2. Firstly, every team needs a local server that represents the team. These local servers should be on-line all the time and connected to a global server that is responsible for the inter-disciplinary collaboration, in the Client-Server mode. The global server manages a unique BIM model with different versions, and updates the data in the local servers instantly. On the other hand, users in each disciplinary team can use their own peer PC to communicate with each other following the P2P network model, and connect to the local server of their team directly or indirectly. Their online status will not affect the operation of other peers or the local server. However, in the client-server network, only one team works on BIM model at any one time and the members of the working team collaborate synchronously in a P2P network.

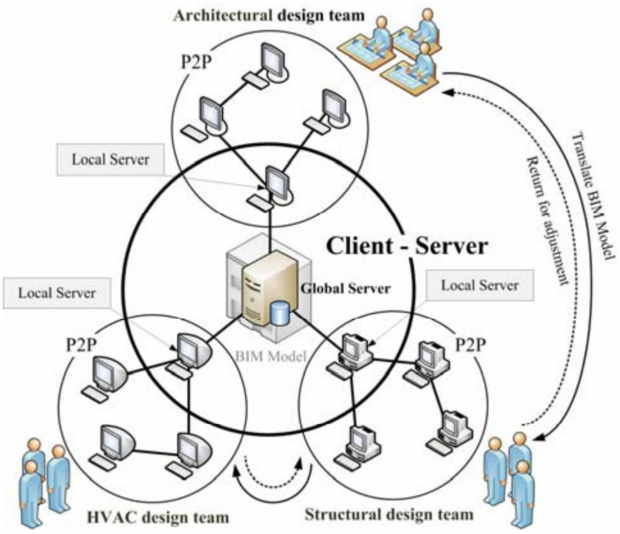

Fig. 2 Hybrid Client-Server and P2P Network Model based Inter-discipline Collaboration Platform.

This study uses the network collaboration method to solve the problems faced by stand-alone CAD systems, and proposes to set up the unified BIM model to achieve the inter-disciplinary collaboration. Based on the integration requirements, this paper proposes to set up the BIM design system to integrate the data among each discipline. The teams of each discipline can work on this virtual platform to assign jobs, cooperate and coordinate with one another to build a final construction model, which reflects the integrated design. Any inconsistencies of the design parameters can be monitored by the system and displayed on the BIM model. It can then be eliminated by further coordination. The teams from different disciplines and the team members from the same discipline can work on the same platform and build a unitary BIM model. This collaborative design process is the same as executing the construction virtually. Since all the design conflicts have been detected and eliminated through the virtual construction process, the actual construction will simply be to realize the BIM model. This can solve the problem faced with a BIM model having being designed by an asynchronous-collaboration inter-disciplinary team. Besides, the inter-disciplinary teams can cooperate and communicate with one another on the system platform to build a BIM model, and to integrate and synchronize the design parameters from different disciplines.

This study also proposes the concept of a sub-model. It extends the normal two-tier BIM model (e.g. building components and the entire BIM model) into a three-tier model (e.g. building components, sub-models and the entire BIM model). This increases the convenience of the BIM model data transmission and integration, and improves the efficiency of collaboration between the inter-disciplinary teams. Furthermore, this study proposes the hybrid Client-Server and P2P network model, which focuses on all the participants in the entire design process. Moreover, the study is based on the analysis of the job assignment and collaboration between each participant. It establishes the network operation model for different participants to collaborate and the method to eliminate conflicts among the inter-disciplinary teams, enabling the inter-disciplinary teams and intra-disciplinary members to coordinate and integrate the design parameters on the shared platform. This leads to the development of an optimal integrated and unified BIM model.

3. SYSTEM REQUIREMENTS

In this study, the relevant functions and architecture plan of a system platform for inter-disciplinary design collaboration for BIM model development were proposed for developing a prototype system. Starting from the system development perspective for fulfilling the functional requirements, some operational mechanisms of the system were proposed as the basis of implementation.

3.1. Sub-model

In order to improve the efficiency of the construction process and increase the data transfer speed, a tier of sub-models between the components and the BIM model was proposed. Therefore, the BIM model in this study has a three-tier architecture. The first tier includes the components. The second tier has the sub-models, which are the building units made up of components from the first tier. The third tier is the entire BIM model composed of the collection of all sub-models. In the network-based inter-disciplinary design collaboration process of construction projects, the inter-disciplinary teams will frequently exchange the BIM model. However, the BIM model records massive volumes of multi-disciplinary design information and is very large. If the entire model is transferred on the network, the large amount of data will incur a heavy burden on the network transmission and slow down the data synchronization. Moreover, when a multi-disciplinary team develops designs for construction projects, they would spend much time on the design of a specific building unit in the model. Therefore, the proposed sub-model tier would divide the BIM model into sub-models, so that the data exchanged during the BIM model design process can be reduced. In addition, one team does not need to wait for another team to complete their designs before they deliver their work. If the predecessor team has already completed some of the sub-models, they will be able to deliver these sub-models to the successor team, so the efficiency of network-based inter-disciplinary collaboration can be greatly improved.

3.2. Online/Offline Mechanism

In the Client-Server network model for inter-disciplinary teams, building the BIM model requires teams from multiple disciplines. The local server of each team must first login to the global server using the team-specific account and password. The team can then be identified and the relevant data of the BIM model design transferred from the global server. The global server can also manage the permissions for modifying existing sub-models of the BIM model, in order to ensure the uniqueness of the sub-models and consistency among the BIM model in different teams. In the P2P network model for intra-disciplinary members, each team has a local server that is the root node connecting peers in the team. The connections between peers form the P2P network model. In this model, every peer can join or leave the team at any time. If one peer wants to join the team online to participate in the design task, the system can use IP broadcasting to search and provide a list of nodes that have enabled server mode from the online team members, other than directly inputting the IP address and port number to assign the target. The peer can then select which one of them to connect to. This feature simplifies the process of connecting to other peers.

3.3. Data Synchronization

In the data management aspect, for the inter-team part, the Client-Server network architecture is used. The global server provides all teams with a data exchange and management center accessible through Internet, which manages the BIM model data generated by every team. The P2P network model is used for intra-team peers. The design data is stored and communicated in the same format, which is a string started by a keyword specifying its type and followed by its individual attributes. On the other hand, each datum must have a unique ID to be distinguished in the distributed environment. In the aspect of data consistency, the permission on each model component can only be granted to one team at a time. The other teams cannot edit the component or modify its related attributes and multi-disciplinary parameters, which ensures the consistency of the model objects among all the teams. In the inter-disciplinary teams, when the team holding the permission updates the BIM model, their local server will upload the new BIM model to the global server, so that other teams' local servers can retrieve the updated BIM model instantly. The local server in a team can centralize and manage the design data and push it to every peer in order to facilitate discussion among the team members. For data exchange among team members, each peer has to notify all the other peers by broadcasting its modification, such as addition, deleting, scaling, or moving a modeling object, to the model immediately after an action is completed and confirmed.

3.4. Access Management

In the inter-disciplinary real-time online collaboration setting, due to the requirement of data consistency, multiple teams or users editing the same model object should be avoided. Therefore, rules on permissions for model objects are required. The model object permission management consists of two parts, namely the inter-disciplinary and inter-team management, and the intra-team user management. For the inter-disciplinary team, the permissions of the sub-models in BIM model are managed and controlled by the global server. The permission for a sub-model in the BIM model can only be possessed by a single team. Only the members of that team can edit and modify the sub-model and its components. Other teams without the permission cannot edit or modify the sub-model, and can only view it. Among the intra-team users, the permission management of the model objects relies on the lock-based mechanism. To ensure that a lock on an object will not be granted to more than one user at any one time, a locked object cannot be requested until its owner releases its lock. To ensure all the locked objects belong to an owner, a peer automatically releases all its locks on objects immediately before leaving the group.

3.5. Data Transmission and Communication Protocols

In both the inter-disciplinary and intra-disciplinary online collaboration environments, inter-team or intra-team exchange of BIM model data is very frequent. The global server, local servers and peers in the teams will receive and process data from different sources at the same time. Therefore, the proposed system in this study employs multithread processing for data from different sources. The global server, local servers and peers can receive data from different sources simultaneously and process them accordingly. Different threads will not interfere with each other. The multi-thread capability included in Java can be used to fulfill this goal by creating multiple threads to run concurrently, and each thread has a connection to another peer. For the inter-disciplinary teams, the data transmission of model objects is managed by the global server. Each disciplinary team has a local server that is always online and in charge of sending real-time model data to the global server and receiving updated model data from it. In the intra-disciplinary team, each peer connects to other peers using the Application Level Multicast (ALM) technique in the P2P network. In the ALM, data is transmitted through the tree-structure overlay network composed of unicasts between nodes in a multicast group, so that the transmission efficiency is improved.

3.6. Version Management

The BIM model version management function and mechanism proposed in this study can effectively manage BIM design data generated in the inter-disciplinary team collaboration, and enhance the efficiency of inter-disciplinary teams' communication, and data recoverability. When each disciplinary team finishes their design and delivers it to the successor team, the global server will automatically keep a record of the delivered sub-model. Therefore, there will be several backups of multi-disciplinary sub-models belonging to different design stages, which can be used to rollback the sub-models later if required. During the design process, when the team in charge at the current stage modifies the sub-model such that it conflicts with the parameters or data designed by previous team, they can choose any of the backups left by the previous team in the global server to rollback to. This feature facilitates the coordination and communication between inter-disciplinary teams in dealing with conflicts in design parameters or data, and improves the efficiency of design collaboration.

4. SYSTEM IMPLEMENTATION

The proposed system can be thought of as a fusion of a CAD program, a communications program, and Web connection program. The proposed system architecture is a four-tier system, as shown on Figure 3.

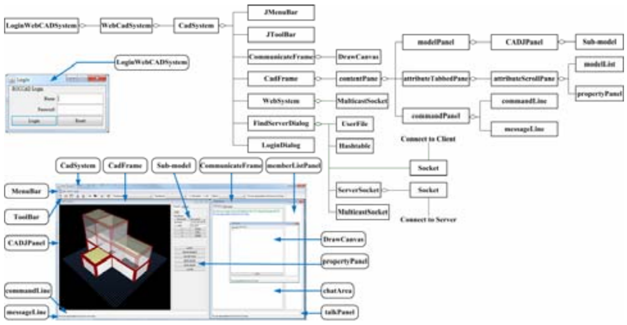

Fig. 3 The object model of the proposed prototype system.

5. CONCLUSIONS

This paper proposes a hybrid network which allows for coordination of interdisciplinary teams in BIM. This network allows designers and engineers to stay in real time communication, and to transmit the attributes of model objects and model parameters. Designers and engineers are thus able to coordinate their development of the model and objects based on the design objectives. This network represents an improvement on traditional collaboration, and will help to improve overall project efficiency.

6. ACKNOWLEDGEMENT

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REFERENCES

[1] Eastman, C., Teicholz, P., Sacks, R., Liston, K., *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors*, John Wiley & Sons, Inc., Hoboken, New Jersey, 2008.

[2] Chou, S.A., Hsieh, S. H., "A Case Study on 3D Collaborative Design for MRT Station", *Proceedings of the International Conference on Computational Design in Engineering (CODE2009)*, in Seoul, Korea, on November 3rd - 6th, 2009.

[3] You, C.-F., Tsou, P.-J., Yeh, S.-C., "Collaborative design for an assembly via the Internet", *International Journal of Advanced Manufacturing Technology*, Vol. 31(11-12), pp. 1217-1222, 2007.