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INTEROPERABILITY ISSUES IN CROSS-DISCIPLINARY COLLABORATIONS OF IRREGULARLY SHAPED BUILDINGS: THE CASE OF DONGDAEMUN DESIGN PLAZA AND PARK

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ABSTRACT: This paper summarizes some of approaches that could be taken for data exchange in a non-interoperable work environment and reports lessons learned from the Dongdaemun Design Plaza and Park project. Today's widespread application of building information modeling (BIM) to the construction and architectural design industries requires a change in the cooperation between business organizations and their methods of communication. In particular, the interoperability of information between interdisciplinary organizations, which use specific programs for different purposes, has become a critical issue. More than just a technical problem, it is also highly related to an organization's collaboration culture and the particulars of a specific project. This paper describes the interoperability issue that occurred during the construction documentation phase of the irregularly shaped building project, Dongdaemun Design Plaza and Park, designed by Zaha Hadid Architects and Samoo Architects and Engineers, from the perspective of the technological problem and the collaborative organizations' communications. Although the perfect compatibility of information is not possible, this paper deals with a practical approach to the interoperability issue by examining the way the end-users of computer-aided design (CAD) resolved the interoperability problems in practice.

Keywords: interoperability, cross-disciplinary collaboration, building information modeling, irregular-shaped building

1. INTRODUCTION

A design and construction process can be regarded as a process of decision making and information production by a number of organizations, including architectural firms. As the use of building information modeling (BIM) has recently become widespread across the board in the construction and architectural design industries, the issue of interoperability among organizations that use a particular program for different purposes has become essential. According to Young et al. [1], this interoperability can be defined from two perspectives. From the technical viewpoint, it can be defined as the capability of management and exchange of electronic products between different computer-aided design (CAD) programs. On the other hand, from a cultural and broader perspective, it can be defined as the collaboration capability to integrate a project amongst teams, blurring the lines between disciplines.

Lee [2] categorized the collaboration capability of BIM into four stages. In Korea, most of the cases are in the first or second stages; that is, BIM use occurs on a person or team level. The third level, inter-team BIM collaboration, is rare. However, there are a number of cases around the world that have reached the fourth level—inter-organizational BIM collaboration. Some such cases of successful BIM collaboration include buildings designed by Frank Ghery, as reported in Yoo et al. [3]. Dongdaemun Design Plaza and Park (DDP), designed by Zaha Hadid Architects Ltd, is one of a few large-scale international BIM collaboration projects in Korea. This paper deals with the perspectives of organizational collaboration and technology on the information interoperability issue that occurred in the construction documentation phase for DDP. The building was designed by Zaha Hadid Architects Ltd in London, and the construction documents were developed and completed by Samoo Architects and Engineers in Seoul, the local partner. The authors of this paper participated in the project, going back and forth between the London office of Zaha Hadid and the Seoul office of Samoo.

DDP is the first irregularly shaped mega-building project in Korea to which BIM was applied from the planning stage. Thirty-eight percent of its exterior skin (about 10,900 m^2) consists of double-curved aluminum panel surfaces. Given that computer modeling leads the design processes for irregularly shaped buildings, parametric modeling software and non-uniform rational B-spline (NURBS) modeling software produced the major information on the building. Two-dimensional (2-D) and three-dimensional (3-D) AutoCAD software was also used. This paper reports the communication and interoperability problems that occurred during the construction documentation phase of the project with special attention to how the project participants, the end-users of the software, resolved the problems.

This study begins with the review of previous studies containing reported cases of BIM use and interoperability problems that arose where BIM was used. Then, a brief description of the DDP project is presented to provide the context of this study. The body of this study is devoted to the description of information flow among organizations in practice, based on the organizational chart, and the interoperability problems that occurred in the design procedure of the various organizations by the use of a specific CAD system. Lastly, practical methods of information sharing and communication are discussed for a successful BIM-based process in a transient period from the design development (DD) phase to the construction documentation (CD) phase.

2. PREVIOUS STUDIES

Fischer and Kam [4] studied problems that occurred during data exchange between the participants in the new auditorium project at the Helsinki University of Technology (HUT-600). Researchers examined the feasibility of various organizations' collaboration using the IFC standard format throughout the entire process of design and construction of the HUT auditorium project, performed for 17 months since September 2000. An architectural model was developed using ArchiCAD, and the model was sent to other applications using the IFC for structural analysis, thermal analysis, and fluid analysis, and using other standard exchange formats for light environment and estimation programs. The use of BIM contributed to both the 50% reduction in time spent producing construction documents and the maximization of building functions via the application of various environment analysis simulations from the design stage. For instance, confusion arose in sharing a model because each organization used its own layer management method, degree of precision, and margin of error due to the lack of standard guidelines for collaborative organizations. Additional confusion resulted from the lack of consensus for layer management and element name management. Some organizations had to substantially modify the existing model in order to use their own applications. HUT-600 confirmed the substantial benefits in the adoption of the IFC standard for collaborative organizations throughout the design and construction. However, the current market situation makes it difficult for each participating organization to buy the same software.

In Korea, Lim et al. [5] tested the compatibility between commercial 3-D CAD systems using the IFC format and data exchange formats such as dwg, dxf, dwf and dfn, provided by software. Although the function of each compatible format was tested, in practice, there is uncertainty about potential compatibility problems because the test used an artificially created model.

Gielingh [6] noted that use of the product data model (PDM) had not been very widely spread for the last 14 years, since the introduction of STEP in 1994, and provided a reason from the perspective of the industry. According to Gielingh, even if the interoperability problem were technologically resolved, it is difficult to assume that all organizations of the industry would use the CAD system suitable for the PDM. Thus, he emphasized the importance of practical and bottom-up approaches that consider the various professions and heterogeneous CAD systems in the current industry. Although no specific examples were provided, it is evidently crucial to understand the complex context of industry and practices so that the information model can overcome interoperability problems and produce actual effects in the industry.

3. DONGDAEMUN DESIGN PARK AND PLAZA

3.1 Brief Outline of the Project

DDP is a cultural facility to be built at the site of Dongdaemun Stadium in Seoul, Korea. The client, Seoul Metropolitan Government, selected the design submitted by Zaha Hadid Architects in August 2007 through a nominated and invited design competition. The design for the prizewinning plan was carried out by forming a consortium between Zaha Hadid Architects and a local architect, Samoo Architects and Engineers, from December 2007 to December 2008. The following is a description of the interoperability problems that occurred in the process of the design development (DD) and construction documentation (CD) phases.

3.2 Organization Structure and Information Flows

To understand the interoperability problems in practice, it is important to understand the organizational structure and direction of information flow among organizations. As noted in the case of HUT-600, each business area requires particular information. In addition, when specific information is exported from one organization to another, and when the same information is imported back to the original organization, in many cases, the attributes and content of the information can change. Figure 1 shows the structure of organizations in the process of DD and CD and describes the flow of information. Further explanation will be provided later.

Due to the short project period, the original designer, Zaha Hadid Architects, had to develop the design even into the CD phase. Architects performed 3-D modeling using Rhinoceros ("Rhino" hereafter) 4.0. In the last stage of DD, the Rhinoceros model contains building skin, floor slabs, interior walls, core, columns, stairs, windows, and landscape. Engineers modeled structure and mechanical, electrical, and plumbing (MEP) using Revit Structure and Revit MEP.

The skin and substructures of the building were modeled parametrically by the Samoo team using CATIA, based on point data received from Rhino during the CD phase. A team of CATIA modeling experts from the automobile industry collaborated and developed the CATIA model. Rhino model information up to the DD stage was imported to the CATIA model. However, both the Rhino and CATIA models were used as the master models, which caused many problems. The Rhino model was used as the main master model. As the Rhino model changed, the CATIA model had to be rebuilt. The next section describes the resultant problems in detail. For the structural part, the CATIA model was deployed as a reference model. Structural engineers received only partial information for structural design from the CATIA model, and the result of structural calculations was then conveyed to architects in text format. In addition, there was another team that focused only on the production of 2-D construction documents. Although CATIA is capable of automatically creating 2-D drawings, the construction documents were generated manually because it was practically impossible for CATIA to create modeling for every part of the building in such a short period of time. The official design submission of the design service was done in the form of 2-D drawings.

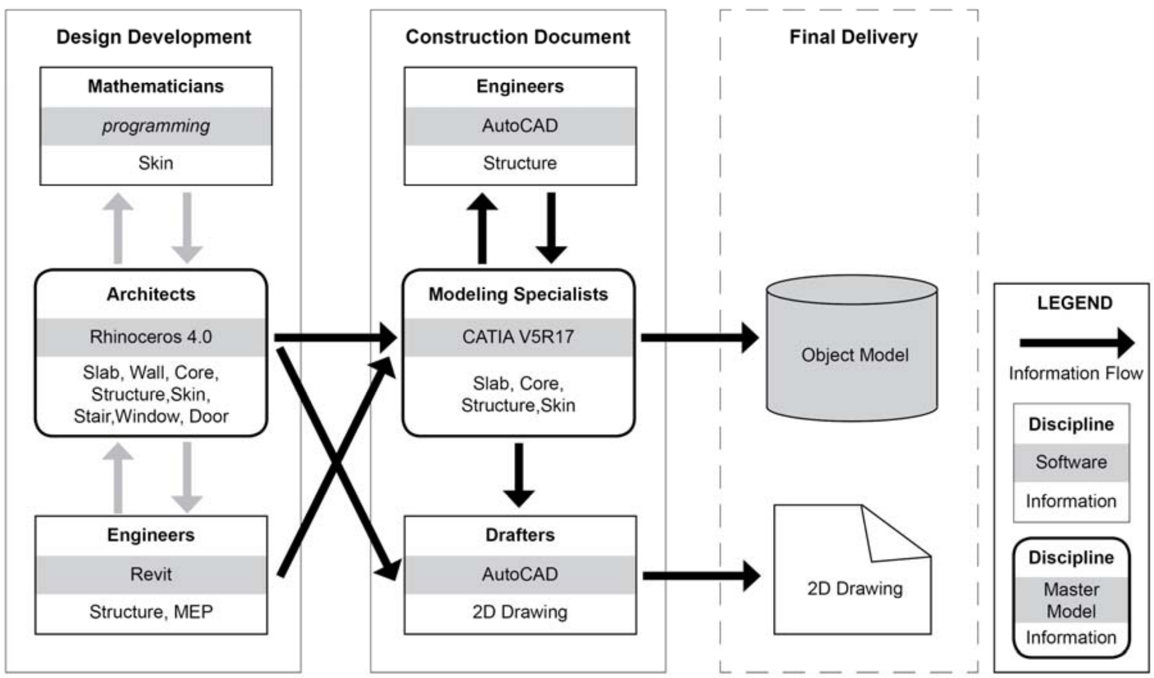

Figure 21 Structure of organization and its information flows

3.3 Interoperability Issues in Transition from the Design Development Phase to the Construction Documentation Phase

In this section, we discuss the interoperability problems that arose in the DDP project, which occurred in the transitional process from the design development phase to the construction documentation phase. The design process up to the DD is to develop the design by reviewing a number of alternatives and determining the final geometric form of the building. On the other hand, the purpose of the CD phase is to produce precise and detailed information for the building's construction. Given these different objectives, using the appropriate CAD tool for each stage's purpose is critical.

In reported existing cases, a parametric model such as a CATIA model was generally used as the master model in the CD phase [3]. However, in the case of the DDP Rhino was used as the master model in the schematic design (SD) and DD phases. Initially, the Rhino model was the main master model also in the CD phase. However, because building skin panels and structural elements were modeled based on a CATIA model that provided accurate and controllable geometry essential for detail and drawing generation, the CATIA model was the de facto master model.

The real interoperability problem developed as a result of the fact that Rhino and CATIA are inheritably different. Rhino, a 3-D surface modeling program based in NURBS, is widely used by numerous architectural practices to generate forms of irregularly shaped buildings. It allows designers to explore alternative building forms easily and intuitively. Because it is not a history-based modeling tool, users can edit and modify any parts of a model without the constraints that may be imposed in a history-based modeling system. On the other hand, CATIA is a solid modeler and history-based parametric modeling system that maintains the order of feature generation as hierarchical and mathematical relationships between features. While these mathematical constraints can significantly reduce modeling time by allowing users to create new or modified shapes by changing parametric values or relations, they also make model manipulation difficult if users want to explore alternative shapes quickly and freely. Another advantage of parametric modeling is that, if some parts of a model are modified, the other parts will be automatically updated based on pre-defined constraints. These fundamental differences between the two CAD systems are the reasons each is preferred in a different design phase, as well as the main reason for partial mismatch between the two master models in the CD phase.

To design the streamlined external shape of the building, architects used Rhino in the SD and DD phases. Numerous alternative forms were created using Rhino during both phases. The Rhino model of the building's exterior determined in the last stage of DD was imported to the CATIA model for CD. As described above, CATIA was used for the exterior panels and their supporting substructure and also as a reference model for main structures and other parts of the building. Once modeling was performed, numerous structural members supporting the complicated geometric exterior of the building could be automatically updated whenever minor design changes were made.

However, a parametrically defined model cannot conform to design changes if topological shapes of a model change, as happened in the CD phase. The panel shapes and sizes had been optimized and changed several times during the CD phase in order to decrease the curvature of panels so that their manufacturing cost could be decreased. This rationalization process changed the size and, consequently, the number of panels. Whenever there was a model update, the CATIA model that had been generated based on previous data could not be reused, and a new model had to be completely rebuilt from data points imported from a Rhino model.

This time-consuming process continued until the end of the CD phase. The final geometry of the exterior shape was up to 10 cm different from that finalized at the end of the DD phase. The difference was minor considering the size of the building, but the workload associated with the changes was enormous.

From this specific case, one major lesson learned was that two BIM systems should not be used as a master model control system. However, if more than two BIM systems must be used to control the geometry of a design, which may happen frequently in real projects, then a system that can handle more geometric information must be contractually the main BIM system. This will help a project team maintain the integrity between models and drawings with much less effort and time.

3.4 Interoperability Issues between Project Participants during the CD Phase

This section covers the interoperability problems that occurred between collaborative organizations in the CD phase and several approaches to solve the problems. As described earlier, each organization used a different CAD system. Figure 2 describes the CAD systems of each organization and the information exchange methods.

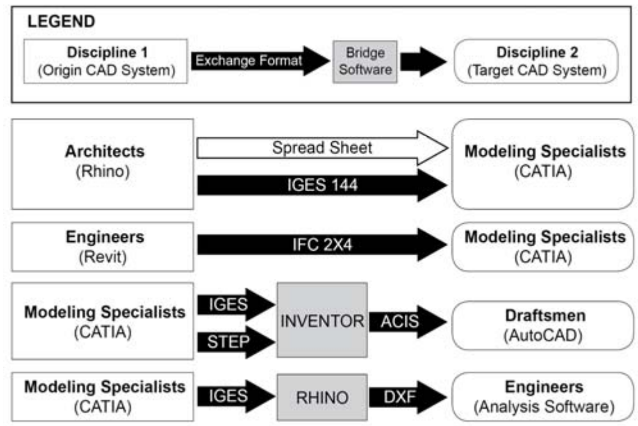

Figure2. Information exchange methods

None of the data exchange between systems was smooth. The first challenge was to find an appropriate exchange format that could minimize reworking. Even if a matching format between two systems was found, it was often the case that non-geometric information could not be transmitted. Non-geometric information was shared by using a novel information management protocol under the mutual agreement among organizations.

For example, although both Rhino and CATIA support the IGES format, there are 60 IGES options for exporting data in Rhino. Since the solid model options did not work, we tested all the options, including those for CATIA solid and CATIA surface models. We found that a model was least impaired when using the IGES144 format. However, even the IGES144 format had some problems. For instance, the surface information sent from Rhino to CATIA using IGES144 was not exactly the same as that of the Rhino model and created wide gaps between surfaces in CATIA. Figure 3(a) shows a portion of the Rhino model, and Figure 3(b) shows the same portion in the CATIA model imported using IGES144. The gaps between surfaces were 1 cm or less. Given the size of the building, this gap may be regarded within the margin of error.

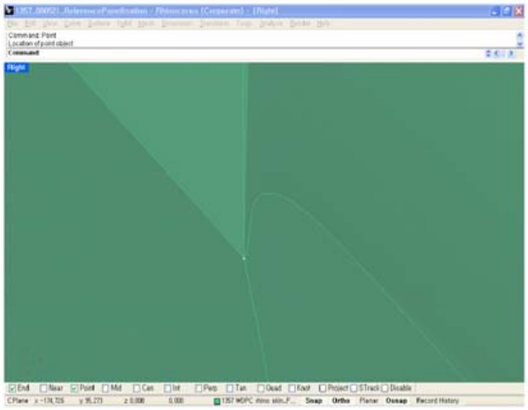

Fig.3(a) Rhino model

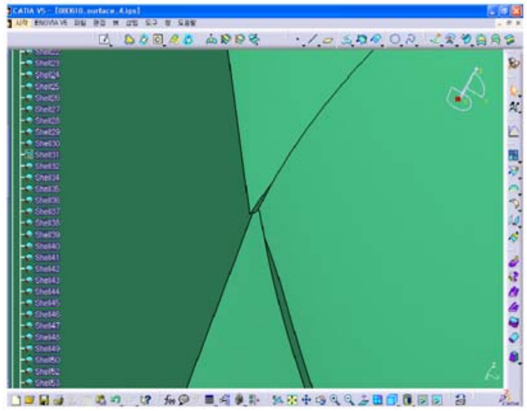

Fig.3(b) CATIA model transferred from Rhino
(The same part with the Fig.3(a))

Figure 3 Distorted surfaces

Yet, even such small gaps cause misalignment and visual discontinuity between panels, which would be immediately recognizable by passers-by. In order to correct this problem, CATIA modelers extracted panel end points from Rhino and created new surfaces using the extracted points as references. Although the CATIA modelers developed some scripts and parametric custom objects that automated part of the modeling process, the process still took a great deal of lot of time and effort.

To realize the design into a building, architects must deliver geometric and non-geometric information that may not be included in a model to other organizations. The facade of the DDP, composed of 50,000 panels, varies in colors, perforation patterns, and light locations. This geometric and non-geometric information was not included in the model, but was delivered as separate documents for fabricators and contractors. In order to make each panel self-explanatory for these manufacturing properties, architects developed a unique panel labeling convention composed of 11 characters that explains the attributes of each panel (see Figure 4).

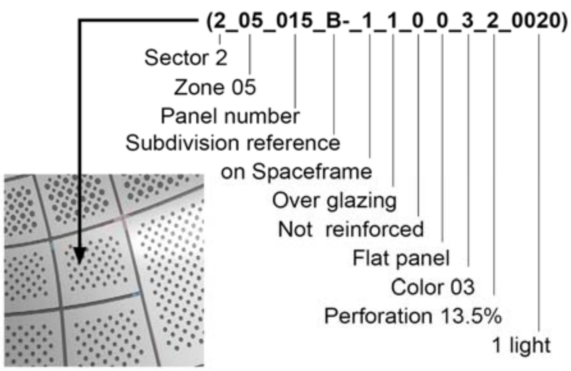

Figure 4 Panel labeling protocol

Construction documents were produced by a separate organization. The information from the Rhino and CATIA models were used to produce drawings. The IGES format was used to exchange the surface information from CATIA, and solid information was exported using the STEP format. However, because AutoCAD does not accept either the IGES or STEP format, the staff could access the information in AutoCAD only after changing the IGES and STEP files into ACIS with a third CAD system, Inventor. This resulted in the impairment of a substantial part of the model imported by ACIS, and additional modeling work had to be done.

Structural engineers required the information on columns, support points for each exterior panel, and the base line for laying out a space frame that would support the building's skin. Since structural engineers used AutoCAD, which lacks a compatible exchange format with CATIA, Rhino was used to convert IGES into the DXF format, which could be read into AutoCAD. In this process, some of straight base lines were unintentionally changed into splines. Because base lines must be straight, engineers reentered the base lines based on base points.

No part of the data exchange process was seamless. The approaches taken to resolve the interoperability problems described in this section and lessons learned are generalized and summarized in section four below.

4. CONCLUSIONS

This paper described the work procedure and interoperability issues that occurred during the CD phase of the DDP project. In practice, it may be more common to work in non-interoperable environments like the DDP project than in a seamlessly interoperable environment. In the DDP project, three main approaches were taken to overcome the limitations. The following generalizes the three approaches and adds another approach that may be taken to resolve exchange problems in a non-interoperable environment:

1) **Reconstruction of a model based on partial information exchanged using a common data format between two systems**: Even if there is a common data format between two systems, it is likely that the information exchanged using the common data format carries only part of information from one system to the other. In such cases, a model needs to be rebuilt based on transferred partial information. Scripting might be helpful to reduce the workload. It should be noted that, even if there is a common data format between two systems, neither full nor partial data exchange between the two systems is guaranteed.
2) **Use of the third CAD program that supports common data formats for both systems**: If there is no common data format between two systems, a third system that supports data exchange with the two systems can be deployed. This project deployed Inventor and Rhino for AutoCAD and CATIA.
3) **Total reconstruction of information**: Sometimes, total reconstruction of information by manual reentry of data is unavoidable.
4) **Development of a translator between two systems**: This approach was not taken in the DDP project. Yet, it is possible to develop a translator between two systems through an open application programming interface (API).

The following summarizes the lessons learned from the project:

- **A parametric model should be used as a master model in the CD phase.**

Using a surface model is adequate in the SD and DD phases, but using a surface model as a master model in the CD phase is not appropriate. Since surface modelers do not provide accurate and controllable geometry, it is difficult to develop construction-level details and documents out of a surface model.

If a surface model is used as a main master model in the CD phase and a parametric model is used as a secondary model for developing panel and structural details, laborious and time-consuming remodeling processes are unavoidable.

- **Agreement must exist on the information exchange formats and methods between different systems.**

No exchange file format, including IFC, can guarantee lossless data exchange. All the project participants must mutually understand the limitations of the exchange formats that are used and develop data exchange scenarios between different systems. In many cases, only partial information can be transferred from one system to another. A data exchange scenario that can minimize rework should be developed, and the project participants should do their best to provide any information required to reduce the reworking by others and to make this scenario function.

This paper summarizes some of approaches that could be taken for data exchange in a non-interoperable work environment and reports lessons learned from the DDP project. As collaboration using BIM tools becomes more common, interoperability issues will be a serious problem. Many organizations including buildingSMART are putting forth many efforts to overcome the interoperability issues. However, the problem will soon become a serious issue in practice, and more concentrated efforts are required.

5. ACKNOWLEDGMENT

This work was supported by the Korean Institute of Construction & Transportation Technology Evaluation and Planning (KICTEP) with the program number of "06-Unified and Advanced Construction Technology Program-E01" and Samoo Architects and Engineers. We are grateful to all the DDP project team members for giving us the opportunity to participate in, observe, and conduct research on the invaluable project, despite their time-constrained nature of the project.

6. REFERENCES

[1] Young Jr., N. W., Jones, S. A., and Bernstein, H. M. "Interoperability in the Construction Industry." *McGraw Hill Construction,* 2007.

[2] Lee, G. (2007). “Collaboration Method for Improving the Efficiency of BIM.” 2007 BIM Workshop. Construction Association of Korea (CAK), Seoul, Korea.

[3] Yoo, Y., R. J. Boland, Jr., et al. "From Organization Design to Organization Designing." *Organization Science* **17**(2): 215-229(15), 2006.

[4] Martin Fischer, Calvin Kam, PM4D Final Report, Stanford CIFE, 2002.

[5] Lim, J., Kim J., Kwon, H., Yoon, S., Kwon, S., Chin, S., “Ifc Test Between Commercial 3D CAD Application Using IFC.”, *Korean Jorunal of Construction Engineering and Management*, Vol.9(3), pp.85-94, 2008

[6] Wim, G., “An Assessment of the Current State of Product Data Technologies.” *Computer-Aided Design*, Vol.40, pp.750-759, 2008