An Industry Foundation Classes Web-based Approach and Platform for Bidirectional Conversion of Structural Analysis Models

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ABSTRACT

Projects in the Architectural Engineering and Construction (AEC) industry involve several organizations and practitioners who require sharing very diverse set of information and models. Building Information Modeling (BIM) and open standards such as Industry Foundation Classes (IFC) have made substantial progress in improving the interoperability in recent years. However, inadequate interoperability is still inflicting an economic burden and is considered one of the main limiting factors for BIM adoption. This paper presents an IFC and Web-based approach and tool that enable a bidirectional conversion among structural analysis models. The approach consists of an IFC-based unified information model and a number of algorithms that help overcoming the differences between the data structures and representation logics of different structural analysis technologies. A web-based platform, that utilizes WebGL, was developed to enable the sharing and converting of different building models. The testing of the approach and the platform developed, in a live case study, demonstrated consistency in the conversion process and stability and rendering quality in the display of models over the Web browser.

INTRODUCTION

The Architectural Engineering and Construction (AEC) industry is a very challenging environment for collaboration and sharing of project information due to the many stakeholders and technologies involved. This is exacerbated by the nature of the industry where teams are often brought together for the duration of the projects. Industry Foundation Classes (IFC) provide the building blocks for interoperability through its open and neutral data schema (Venugopal et al., 2012). The efficient interoperability is considered one of the factors influencing the value proposition of Building Information Modeling (BIM) in industry and streamlined information flow between different disciplines (Young et al., 2009). Major challenges are associated with export and import functions for the same data, posing a barrier to the advance of BIM (Eastman et al., 2010). In the case of round trip exchanges, the receiving application should be able to interpret the design intent and the original shape composition; otherwise the original information is lost (Venugopal et al., 2012).

Research into interoperability enhancement has received an increasing attention over the last decade (Weise et al. 2003; Chen et al. 2005 and Serror et al. 2008). Jim et al. (2012) presented lessons learned from BIM models between various tools and identified that the most significant challenge at semantic level is inconsistency of modeling style. According to the authors, solutions to this issue could be either methodological such as defining consisting modeling styles or technical such as using ontologies or building transformation bridges.

Hu and Zhang (2011) developed a BIM integrated dynamic environment in which a structural information model provides a universal data source of data which share all relevant information with connected applications. Wan et al. (2004) developed a building model server for supporting data integration between IFC and SAP2000 which is a commercial structural design application. Liu et al. (2010) developed an IFC-based integration tool for information exchange through IFC between an architectural model and a PKPM structural model. Qin et al. (2011) proposed a model transformation system by defining an IFC-based BIM and XML-based Finite Element Method (FEM). Wang et al. (2013) developed a software tool that enable extracting the information of IFC structural models to form a corresponding structural model.

Most of the aforementioned studies are mostly client-server applications or just provide one-way trip. On the other hand, the advent of BIM servers such as IFC Model Server, EDM Model Server, BIM Server (Eastman et al. 2010), etc., helps the development of solutions for the integration, management and sharing of building information. Moreover, new Web standards such as HTML5, that support WebGL, are providing the premises for 3D graphics display in browsers and are the foundation of future embedded rich Web applications. For example, WebGL has been used in 3D visualization of CityGML (Gesquiere & Manin 2012) and bioWeb3D (Pettit & Marioni 2013). Also WebGL applications that support IFC-format, such as BIMSurfer and IfcWebViewer, have been developed. In other industries where very large data sets and models are utilized such as the oil and gas sector, the development of WebGL-based information integration approaches and technologies is under way (Rasys et al., 2013). WebGL is emerging as one of the most popular frameworks for the 3D content presentation over the Web (Ortiz Jr., 2010). In this research, Three.js, a fast object oriented JavaScript library that support file formats and math operations (Rasys et al., 2013), is utilized to develop the application for displaying 3D elements on the Web.

This research focuses on the conversion processes between different models and proposes an IFC and WebGL based approach and tool for bidirectional conversion of structural analysis models. The approach, the tool and their empirical testing in a case study are presented in the subsequent sections.

IFC-BASED UNIFIED INFORMATION MODEL

The core element of this approach is an IFC-based unified information model (Figure 1) which acts as a central data server, coupled with networking technologies, to facilitate information exchange among various participants. The unified information model extracts and expands the information from IFC models and stores architectural information, structural information and their shared information in a structured way (see Figure 1). The extracted architectural information comprises all elements that make up a building while the structural information includes only all structural elements such as *IfcBeam*, *IfcColumn*, *IfcWall* and *IfcSlab* and their attributes. Other related information, including boundary conditions, different structural loads, load cases and their combinations, is also added to the structural information in the unified information model. Material and profile properties are also included under the *IfcRelAssociates* entity. This unified model complies with the structure and definition of model views, as a subset of the exchange schema, as suggested by Venugopal et al. (2012). The structure and content of the unified information model has the necessary information for enabling transformation among different building models including architectural model, structural model and structural analysis model.

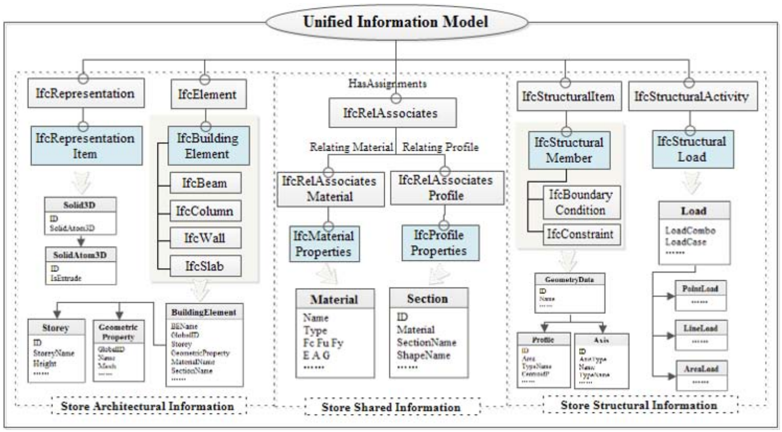

Figure 1. Data structure of the unified information model

ALGORITHMS FOR CONVERSION AMONG DIFFERENT MODELS

An architectural model is used to mainly describe the geometry and appearance representation of the building while a structural model consists of structural elements that are specified for vertical and lateral load transferring. Based on structural models, structural analysis models are developed by structural engineers by adding different load cases, geometric boundary conditions, etc. The proposed algorithms has to be capable to perform the conversion among these three types of models (see Figure 2).

Conversion algorithm from architectural model to structural model. This algorithm enables the extraction and classification of key information of the architectural model that need to be processed and transmitted to the structural model (see Figure 2). For frame structures, the axis and section information from the architectural model are extracted and the node tolerance on the non-coinciding segments are then calculated in the structural joints. The analysis of corresponding information according to different situations was detailed discussed in our previous work (Hu 2008). For shear wall structures, the algorithm classifies the type of wall based on the thickness. If the thickness of the wall is less than 160 mm, the wall is considered as an infill wall and is ignored. If it is more than 160 mm, the algorithm captures the material of the wall. If it is a reinforced concrete wall, the algorithm will consider it as a shell wall and then deliver it to the conversion process.

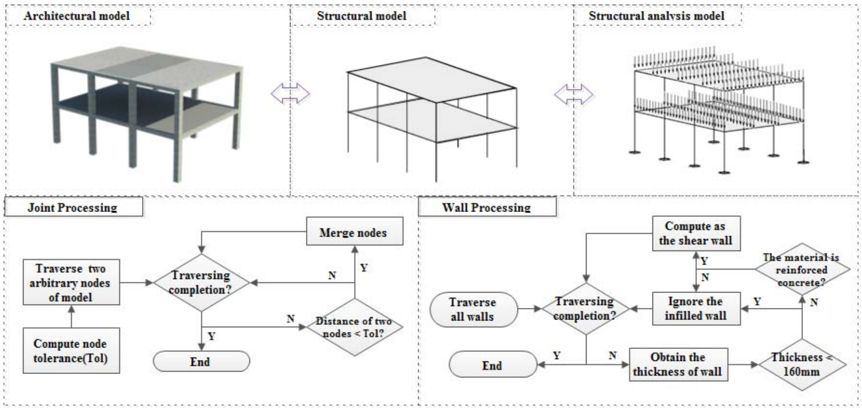

Figure 2. Three types of information model and the conversion process from architectural model to structural model

Conversion from structural model to architectural model. The core idea of this algorithm is to extract the topology information of the structural elements by retrieving the outlines of the corresponding architectural ones. The algorithm distinguishes between a "line" model and an "area" model (see Figure 3). For a "line" model representing elements such as beam, column, brace, etc., the information extracted consist of the axis and section information. For an "area" model representing elements such slab, wall, etc., the outline, thickness and offset of the area need to be captured so as to establish the corresponding architectural model.

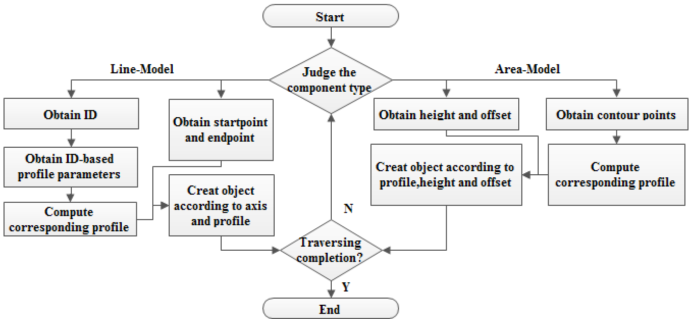

Figure 3. Algorithm from structural model to architectural model

Conversion among various structural analysis models. Complex building projects usually involve several engineering consultants performing structural analysis utilizing different technologies and software applications. Data transformation between different structural software applications is complex because of the inconsistency and incompatibility in the data conversion process. However, most mainstream structural analysis systems use similar modeling techniques and support text-based documents as their input/output files. The proposed unified information model to convert among these various structural analysis models adopts a text-based transformation (see Figure 4).

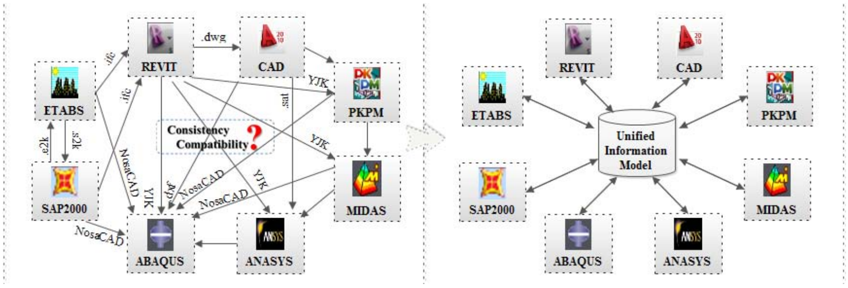

Figure 4. Model conversion among various software applications

A major challenge in the mapping process is the variety of representations of properties of structural elements within different systems. Figure 5 shows the different representations of point information in different structural analysis systems.

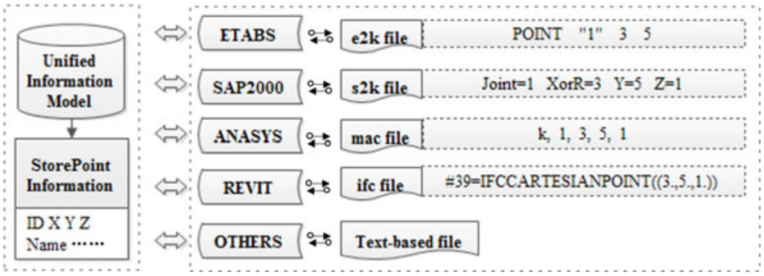

Figure 5. Different representations of point information in various model files

To overcome this challenge, in the proposed solution, interfaces for data mapping and validation are implemented between the unified information model and commercial structural analysis systems. Another challenge in the conversion process is that elements' coordinates vary among structural analysis systems. For example, in ETABS, the abstract local storey-based coordinates are used to refer to the position of elements, while in others systems the global Cartesian coordinates are used. Therefore, when points' information is obtained from the unified information model, the algorithm (see Figure 6) will resolve these inconsistencies during the conversion process. The proposed algorithm, by analyzing the data structure and information representation of different models and establishing a valid mapping between the unified information model and commercial structural analysis systems, enables the conversion among different structural analysis models.

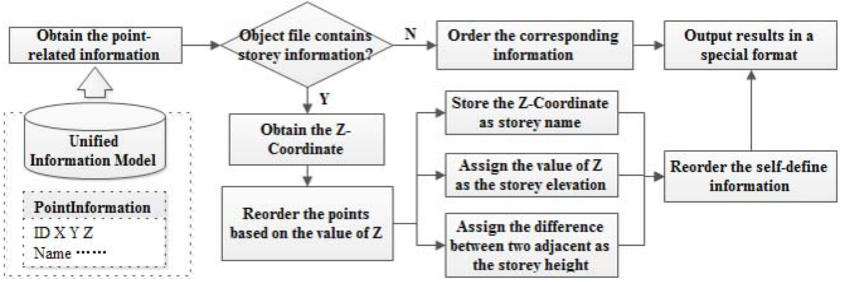

Figure 6. The different process of point information

WEB-BASED PLATFORM

The integration and conversion solution tools are mostly client-server (C/S) based. New web standard such as HTML5 support WebGL technology which is used in this research to achieve model transformation and 3D display of BIM models on the web. Figure 7 illustrates the framework and work flow of the platform. First, users submit their model files in a special format to the server. The server triggers a corresponding application to display the 3D model. Then the model editing/check, model rendering, properties view, etc. can be achieved. Finally, users can export to other commercial structural analysis systems as required.

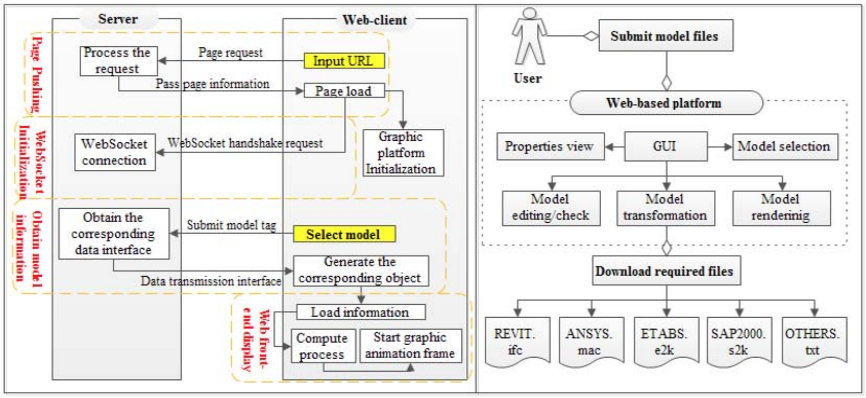

Figure 7. Framework and application flow work of the platform

CASE STUDY

The testing of the proposed approach and the web-based platform was performed in a real life project as shown in Figure 8. A 35-storey model of a commercial building was utilized as a case study. The structural model was firstly established in “e2k” format (an ETAB file). Using the proposed unified information model, the whole building model of about 35,000 objects was converted to .e2k, .s2k and .mac format files within 2.7s, 2.9s and 1.7s, respectively. The sizes of the three files range between 348kb to 720kb. The tree structure of the imported file could be displayed and checked and the properties of the selected element could be extended. The application also demonstrated that geometric data, basic material and section properties could be converted correctly, while transformation of loads, constraints should be further supported in the future versions. In terms of performance over Web browsers, the WebGL viewer demonstrated stability and rendering quality. The interactive features involved (e.g. rendering, editing, submitting, etc.), tested with the involvement of end users, have performed according to the specification. Currently, the Chinese version of this platform is free for users and after the internal trial period, it will be freely opened in both Chinese and English.

CONCLUSIONS

This study presented a novel approach and platform for the bidirectional conversion among structural analysis systems. The proposed approach and

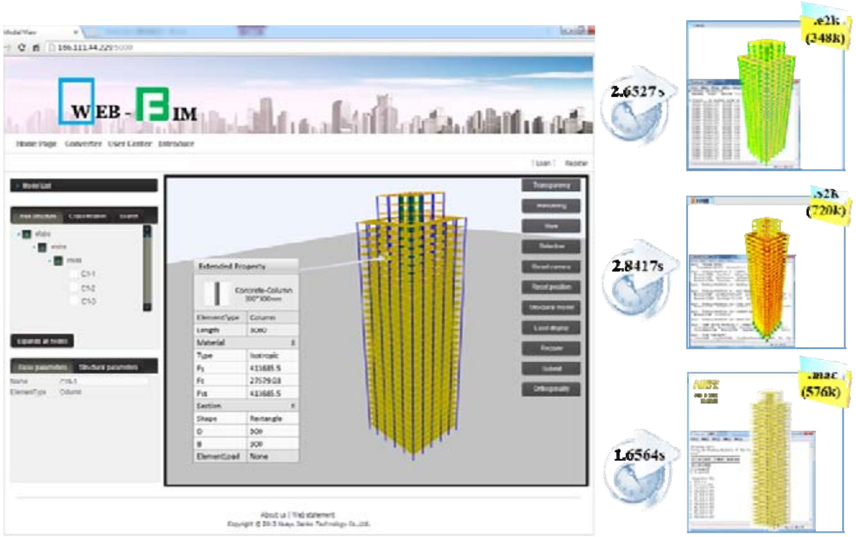

Figure 8. Testing of the Web-based platform

developed platform exploited the concept of BIM and emerging Web technologies such as WebGL. The IFC-based unified information model, augmented with algorithms for the integration and mapping of information and data, enabled the bidirectional conversion among different structural analysis systems. The unified model and the conversion algorithm were integrated into a web-based platform that allowed sharing and converting of structural models. The developed platform also provided additional features such as model editing, view transition and information management that can be interacted over the Web. As a result, the proposed approach and platform are promising in terms of ensuring the consistency and reliability of converted information and the subsequent reduction of repetitive modeling work.

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