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Interpretation of structural analytical models from the coordination view in building information models

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ABSTRACT

Structural design/analysis is one of the most needed uses of Building Information Modeling (BIM). Transforming a building information model to an engineering analytical model is tedious and time-consuming. In addition to geometry transformation, extensive modifications and interpretations are required to make the complex transformed model ready for analysis. Despite such a recognized need, Industry Foundation Classes (IFC) has not been developed sufficiently in engineering analysis uses of BIM as much as it is in some other uses such as design coordination and facility management. As a contribution to addressing this void, development of a new mechanism is discussed in this paper for transformation of IFC building information models in the Coordination View to their equivalent structural models in IFC Structural Analysis View. Considering IFC as the input and output file formats of the mechanism significantly increases the level of interoperability in the proposed model interpretation process. This mechanism is designed to automate the required transformation, modification, and additions operations during such information exchanges. To illustrate feasibility of its implementation, a tool is introduced to automate the developed Interpreted Information Exchange (IIE) mechanism, and its application through a case study serves as validation of the mechanism. The designed IIE mechanism can be extended to automate additional structural modeling tasks. The IIE concept is also applicable to other uses of BIM, especially engineering analysis uses, in order to automate creation of analytical modeling from building information models.

1. Introduction

Emerging Building Information Modeling (BIM) has significantly altered the way construction projects are conducted [1–3]. BIM could be incorporated for different purposes throughout various stages of buildings' lifecycle, engineering analysis being one of them [1,4–8]. According to CIC Research Group [9], engineering analysis BIM Use is a process for determination of the most effective engineering method using intelligent tools, design specifications, and building information model. Saving time and cost by automating the process, which has resulted from rigorous and reliable analysis, and achieving better quality and higher performance in buildings are the most significant potential values of using BIM for engineering analysis purposes [10–13]. According to Schinler and Nelson [14], departing from the traditional implemented process for engineering analysis, engineers can shorten the time they spend on modeling, design, and coordination with other disciplines. To be able to use building information models for engineering purposes, high level of interoperability is required between BIM authoring tool and engineering Design/Analysis (D/A) software [15]. During the past decade, many efforts have been made to present redundant and seamless infrastructures, workflows, and tools to extract information from building information model for use in engineering D/A tools [16,17]. These efforts could be classified in two categories: technologies for standardization and software solutions. In the first category, efforts are focused on the process of information exchange and flow of information throughout the project phases between different disciplines. This mostly includes identification of exchange requirements and standardization of digital representation of exchanging information in IFC language as a BIM open standard file format [18,19]. Examples are Information Delivery Manuals (IDMs) and Model View Definitions (MVDs) developed for different engineering purposes [2,20–23]. In the second category, efforts are focused on development of tools to support information exchange processes. These tools are developed in different forms such as stand-alone software, add-ons, or plug-ins for server-based platforms such as BIMserver [24].

IDMs and MVDs developed by Virtual Building Laboratory (VBL) for

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architectural design to structural design information exchange and that of structural design to structural analysis exchange are examples of efforts made in the first category. These IDMs and MVDs are developed to standardize information exchange from architectural building information models to structural building information models with focus on the building geometry and spatial elements, and also exchange from structural design building information model to analytical structural models with emphasis on geometry of elements along with their structural information such as assigned material, cross sections, loads, load cases, etc. [25]. Another example is IDM and MVD developed by U.S. General Services Administration (GSA) for conceptual design to building energy analysis. This IDM/MVD is used for extracting required architectural information to form the basis of energy analysis. The focus of this IDM/MVD is mostly on space geometry and identifiers, space boundaries, construction types, material and material layers, and building elements that generate second-level space boundaries [25].

There are several examples for efforts made in the second category to facilitate information exchange related to different types of engineering analysis BIM Use. Liu et al. [26] developed an integration tool to improve the IFC project file and export the structural model to PKPM structural analysis tool file format. The algorithm used for developing the tool contains four main steps, consisting of reading structural related building element such as beams, columns, braces, and walls; identifying relationship between elements; determining connections between elements; and analyzing the intersection relationship. The tool was developed by mixed language use of FORTRAN and C++, where classes and functions were written in C++ and the Main part that uses the functions and classes were developed in FORTRAN. Hassanien Serror et al. [27] came up with an infrastructure, called Shared Computer-Aided Structural Design (sCAsD), for earthquake simulation of a structure using IFC file format within DOSE integrated construction management software environment. The whole process of information extractions and data processing in this tool could be divided into four steps consisting of defining structural dynamic actions and boundary conditions, defining entities and their relationship for the FEM model, assigning measurement entities from the IFC Resource layer to the structural analysis model, and integrating structural analysis and architectural models. Zhang and Issa [28] developed a tool in Java language to partially extract information from IFC files. This tool benefits from IFC format "ontology" and an ontology-augmented model index such that the extracted data that follows the former is slightly manipulated to be consistence with the latter defined by the tool developer. Ontology is an explicit specification of a domain that describes the objects and their relationships in that domain [29,30] and it defines certain knowledge classes and hierarchy of a domain based on its fundamental scheme [31]. The algorithm that this tool uses for data extraction has four main steps consisting of development of an augmented ontology model, finding targeted entities and seeking upward to find container entities, seeking downward to find referenced or related entities, and reassembling of the extracted entities and information. This methodology has the potential of being used for information extraction regardless of the ontology considered. Won et al. [32] used a similar algorithm for extracting the required information independently from the data structure defined in IFC schema. Wang et al. [33] developed a tool to extract information required for structural D/A from IFC file of structural BIM. The extracted information in this tool contains five main parts consisting of information related to unit system, material information, member section properties, information related to member joints, and loading information. Qin et al. [34] used an xml-based unified FEM format and programmed with C++ language for bidirectional conversion of information from IFC file format and translating it to different proprietary structural analysis file formats. To support the proposed method, the authors mention the following two main advantages of using XML-based unified FEM as a link between IFC file and proprietary file formats: 1) since it is independent from IFC schema and proprietary file formats of the FEM software, it is easy to upgrade and maintain, 2) it is open, compact, clear, and as a result suitable for making bidirectional interfaces with numerous FEM software packages. Polter et al. [35] presented an under development integrated cloud-based structural analysis platform that uses IFC file of the structural analysis model for some minor design iterations such as thickness of a wall. The rationale for this research [35] is to develop a web service that makes advanced structural analyses that need very high-speed computers affordable for companies and research facilities. The workflow of using this system includes the following six steps: 1) preparation and uploading structural FEM model IFC file, 2) defining desired variation parameters in a XML-based format, 3) providing further relevant information on the web GUI environment, 4) creating variant model by Model Generator unit of the platform based on the input IFC file and variant parameters, 5) analyzing variant models, and 6) sending results to the Data Manager unit for comparing and making it ascribable through the web GUI. Zhang et al. [36] developed a web-based platform for bidirectional conversion of the architectural IFC model to proprietary structural modeling software file formats such as e2k and s2k. The core element of the approach taken in the aforementioned research is development of an IFC-based unified information model for data stored on the cloud space. This information model specifies the information necessary to be extracted for generating structural model of the building. An algorithm was developed in the aforementioned research to extract each piece of information specified in the unified information model from architectural BIM.

Structural design and analysis is one of the most used types of the engineering analysis BIM Use. In such Use, designers use building information models for generation of structural analytical models instead of making analytical models from scratch. This would significantly shorten the engineering modeling time and increase accuracy of analytical models as a result of better coordination between the analytical structural and building information models. According to the McGraw Hill Construction [37], after energy performance analysis, structural analysis has the lowest value/difficulty ratio among different engineering analysis BIM Uses, while it has the highest frequency index (represents how often BIM is used for a process). This demonstrates that interoperable information exchange for structural analysis is so much in demand and the level of interoperability is not high enough to make this BIM Use efficient. Hence, there is a great potential to benefit from employing BIM for structural design purposes only if the interoperability level between different BIM authoring tools and structural D/A software packages can be increased. Currently, BIM authoring tools cannot export structural analytical models in non-proprietary file format. For example, Tekla is capable of exporting structural analysis models to th3 proprietary file format of common structural tools such as SAP2000 and STAAD. Another example is the connection that exists between Autodesk Revit and Robot Structural Analysis Professional. As a result, many attempts have been made to develop tools, as discussed earlier, to connect them to some of the most common structural D/A software packages. To address this issue by using open standard file format, a mechanism is presented in this paper for interpretation of structural D/A models directly from architectural models in IFC format. This mechanism is developed using the methodology for documentation of Interpreted Information Exchange (IIE), which is developed by the authors as other part of this research [38]. A tool is developed based on the presented mechanism to automate model interpretation. Since Coordination View Version 2.0 (CV V2.0) is the most commonly implemented MVD in the BIM authoring tools, both the mechanism and tools are designed to import architectural model in this format. CV V2.0 is developed for IFC 2×3. However, the mechanism and the tool presented in this paper are also compatible with the updated version of this MVD, which is Design Transfer View Version 1.0 (DTV V1.0). Contrary to the discussed tools that are available for generation of structural models from architectural models, this tool does not rely on any proprietary file format for either importing or exporting information as it uses open standard file format for both purposes. The output