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Improving interoperability between architectural and structural design models: An industry foundation classes-based approach with web-based tools

Zhen-Zhong Hu [a,*], Xiao-Yang Zhang [a], Heng-Wei Wang [a], Mohamad Kassem [b]

[a] Department of Civil Engineering, Tsinghua University, Beijing, China
[b] Technology Future Institute, Teesside University, Middleborough, UK

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ABSTRACT

Medium and large construction projects typically involve multiple structural consultants who use a wide range of structural analysis applications. These applications and technologies have inadequate interoperability and there is still a dearth of investigations addressing interoperability issues in the structural engineering domain. This paper proposes a novel approach which combines an industry foundation classes (IFC)-based Unified Information Model with a number of algorithms to enhance the interoperability: (a) between architectural and structural models, and (b) among multiple structural analysis models (bidirectional conversion or round tripping). The proposed approach aims to achieve the conversion by overcoming the inconsistencies in data structures, representation logics and syntax used in different software applications.

The approach was implemented in both Client Server (C/S) and Browser Server (B/S) environments to enable central and remote collaboration among geographically dispersed users. The platforms were tested in four large real-life projects. The testing involved four key scenarios: (a) the bidirectional conversion among four structural analysis tools; (b) the comparison of the conversion via the proposed approach with the conversion via direct links among the involved tools; (c) the direct export from an IFC-based architectural tool through the Application Program Interface (API), and (d) the conversion and visualization of structural analysis results. All these scenarios were successfully performed and tested in four significant case studies. In particular, the conversion among the four structural analysis applications (ETABS, SAP2000, ANSYS and MIDAS) was successfully tested for all possible conversion routes among the four applications in two of the case studies (i.e., Project A and Project B). The first four steps of natural mode shapes and their natural vibration periods were calculated and compared with the converted models. They were all achieved within a standard deviation of 0.1 s and 0.2 s in Project A and Project B, respectively, indicating an accurate conversion.

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1. Introduction

The multitude of disciplines, technologies and teams and the multi-phased and temporary nature of project in the construction industry make them very challenging environments for information management and collaboration. Inadequate integration and interoperability are still inflicting an economic burden and are often considered key factors inhibiting the diffusion of innovation systems in the design, construction and operation (DCO) industry. Within the structural engineering domain, building projects typically involve several consultants and engineers performing structural analysis utilizing different technologies and software applications. Structural analysis processes require them to share very diverse set of information and data models. In the absence of integration solutions between various structural analysis technologies, this task is very challenging, time and resource consuming due to the amount of manpower required for re-modeling work and resolving inconsistency and incompatibility issues. Therefore, it is of paramount importance to develop approaches and tools that can provide an efficient conversion of data models between such technologies with adequate quality and fidelity levels.

Building Information Modeling/Model (BIM) technologies and workflows are increasingly adopted in the DCO industry. A BIM is a digital, parametric, intelligent and object-based representation of the physical and functional characteristics of a building creating a shared database and knowledge resource for project and building information [1]. With the emergence of BIM, open and neutral data schemas were developed to enhance interoperability [2]. Interoperability is considered a key factor in streamlining information flows between different disciplines and influencing the value proposition of BIM in industry [3].

* Corresponding author. Tel.: +86 1062789225.
E-mail addresses: huzhenzhong@tsinghua.edu.cn (Z.-Z. Hu), zhangxiaoyang13@mails.tsinghua.edu.cn (X.-Y. Zhang), whw13@mails.tsinghua.edu.cn (H.-W. Wang), m.kassem@tees.ac.uk (M. Kassem).

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Interoperability challenges are often associated with the export and import capabilities of data models among different technologies which is one of the barriers to BIM advancement [4].

In this paper, we aim to address the conversion challenge between architectural models and structural models and among different structural analysis models. First, we review available studies in this area and we discuss the challenges of converting models between several structural analysis applications. Second, we present a BIM-based approach and its components which include: the IFC-based Unified Information Model; the conversion algorithm between BIM architectural models and structural models, and the conversion algorithms among various structural analysis models. Third, we illustrate the implementation of the proposed approach which included: Client Server (C/S) and Browser Server (B/S) technologies to transfer and display the model, and algorithms for the optimization of transmission. Finally, we explain the workflow and demonstrate the results from deploying the platforms in four complex and very large real life construction projects which were used as case studies to verify the conversion process.

2. Interoperability and integration enhancement: related studies

The multidisciplinary nature of BIM is now widely acknowledged within by the DCO industry [5]. Yet, interoperability issues still persist among various BIM technologies [5]. McGraw Hill [3] states that 8 in 10 users of BIM technologies in the United States consider the lack of interoperability a limiting factor in achieving the full potential of BIM.

Over the last decade research and development activities aimed at enhancing interoperability attracted a significant interest from both industry and academia [6–8]. The common overarching aim among these efforts is to improve the usability of BIM for various stakeholders in the DCO industry. Although IFC is a rich and neutral schema, exchanges of project data using the IFC can be affected by inaccuracies due to inconsistencies in different implementers [2].

In industry, major efforts to enhance interoperability are being undertaken by buildingSMART. They proposed the Model View Definition (MVD) as a key concept to address the interoperability challenge. An MVD is a domain-specific subset of the IFC data which can be used to exchange information for specific purposes between project partners. One of the first and most popular views is the Coordination View [9]. This view is extensively implemented in most of the commercially available BIM technologies. It allows the sharing of BIMs between the major disciplines of architecture, structural engineering, and building services (mechanical) [10]. However, the support of round-trip scenarios is excluded from the support of the Coordination View [10]. In structural domain, the IFC2x3 Structural Analysis View covers the exchange requirements to transfer the structural analysis model to one or many structural analysis applications. However, it only defines the information that is exchanged between the structural design applications and structural analysis applications. The exchange between architectural design and structural design is not addressed by this view and the ways to transfer and re-use such information at project level still requires investigation efforts [11]. Another significant development by buildingSMART is the IFC4 Design Transfer View (IFC4 DTV V1.0) which was released on 10.07.2015. The objectives of the IFC4 DTV V1.0 are to enable collaboration on design elements impacting multiple disciplines and provide the capability of handing over design models to others. The support of round-trip scenarios is excluded from the scope of the Design Transfer View [12]. Given its recent release, there are no commercial software tools that are compliant with this view yet.

Steel et al. [13] presented lessons learned from the translation of BIM between various tools. The semantic incompatibility in representing product data in different authoring tools was identified as the most significant challenge. The semantic interoperability can be addressed in two ways: methodologically by defining consistent modeling styles, or technically by defining ontologies and building bridges that enable transformation. Nawari [14] addressed this challenge for wood structure. The approach used consisted of standardizing BIM using the Information Delivery Manual (IDM) and MVDs to provide a reference to data required by the wood structure design process. Sanguinetti et al. [15] presented an MVD-based system architecture approach to facilitate support for an open-ended set of analysis and assessment tools to enable feedback during architectural design. Jeong et al. [16] proposed a new approach to translate between BIM and Building Energy Modeling (BEM) using MVD.

Chi et al. [17] identified the impact and future development trends for current structural design practices. Processes for systematic modeling and interfaces for data exchanges were identified as key trend to enhance the structural design [17].

Table 1 summarizes and compares the key related studies on model conversion. Chen et al. [18] developed an IFC-based web server to generate structural models from the corresponding IFC-based architectural models. Redmond et al. [19] proposed an integrated platform that exploits the capability of ifcXML[1] or Simplified Markup Language[2] (SML) in enhancing the BIM usability experience for various disciplines and facilitating their early input to the design phase. Deng et al. [22,23] developed an algorithm to automatically generate structural models from the IFC-based architectural model, which was based on a transformation mechanism between an IFC-based BIM and an XML-based Finite Element Model (FEM). Liu et al. [24,25] proposed an integration tool for exchanging information between an IFC architectural model and a PKPM[3] structural model, and a conversion platform to convert between two structural engineering tools (i.e. ABAQUS and SATWE). A similar but more universal approach was proposed by Hu and Zhang [26]. Their approach aimed to achieve a BIM-based dynamic and integrated environment for conversion among structural information models. To deliver this environment, they proposed a universal data source that shares relevant information with the corresponding linked structural analysis applications. Wang et al. [27,28] proposed, using the ObjectARX—an Application Programming Interface (API) that is supported by AutoCAD, a software application within the AutoCAD environment to generate the information of IFC structural models and transform it into the corresponding structural model.

As indicated in Table 1, the majority of the reviewed research efforts are implemented as either standalone or C/S applications, provide one-way trip conversion only, and do not have the capability to convert between both an architectural BIM and a structural BIM and among multiple structural analysis models.

The development and implementation of solutions for the integration, management and sharing of building information can be supported by BIM servers such as IFC Model Server, EDM Model Server and BIM Server [29]. Emerging web standards, such as HTML5 and WebGL, also provide routes for developing solutions for displaying 3D shapes in browsers which can be supplemented with embedded metadata to form rich web applications [30]. For example, 3D visualization in CityGML was enabled using WebGL [31] and 3D visualization in browsers using HTML5 is explored in bioWeb3D [32]. Efforts that are more pertinent to the building sector are those attempting to develop WebGL applications that support the IFC format. Key initiatives in this area include the BIMSurfer, IfcWebViewer and XBIM. In other industries such as the oil and gas sector, where data sets are very large, WebGL-based approaches and technologies for information integration are also being explored [33] in combination with Three.js, a fast object-oriented and high level JavaScript library [34].

[1] IfcXML files are domain specific type of XML files which are generated from BIM's IFCs with data instances identified through unique identifiers which are used to connect one data instance to other [20].

[2] Simplified Markup Language (SML) or simplified XML is a schema used for the extraction of partial data for exchanging information through an internet-based service [21].

[3] PKPM is a widely used structural engineering software in China, developed by China Academy of Building Research Technology which is one of the China's top DCO software firms.

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