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# Model Information Checking to Support Interoperable BIM Usage in Structural Analysis

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## ABSTRACT

Building information modeling (BIM) is widely used in the architectural, engineering, and construction (AEC) domain to support different applications such as cost estimation, planning & scheduling, and structural analysis. Structural analysis is an essential way to ensure structural safety. However, different structural analysis software may not process all information from building information models (BIMs) correctly, which impedes BIM interoperability. To address this problem, the authors proposed a new method for automatically checking information completeness of BIMs to support BIM usage in structural analysis in an interoperable manner. The method was tested in an experimental implementation using python programs and a structural analysis software. The checking results using the proposed method was compared with results from a manual checking and a Model View Definition (MVD)-based checking, respectively. The experiment showed a comparable or better performance of the proposed method in accuracy and efficiency than manual checking and MVD-based checking. Furthermore, the proposed method overcomes the scope limitation possessed by MVD-based checking. Therefore, the proposed information checking method is expected to support BIM interoperability by helping people identify missing information from IFC-based BIMs. The authors also proposed a new system model for the BIM information checking domain [i.e., information, model, application, and application context (IMAAC) model].

## INTRODUCTION

Missing information or information inconsistency is a crucial problem of BIM interoperability among different architectural, engineering, and construction (AEC) domain applications. In the architectural model and structural model of the same building, the same information (such as material information and geometric information) may need to be reviewed and analyzed by different users through different software. Architectural model is a type of scale model, which could reflect the real structural features and provide main information for structural model (such as building elements and connection nodes). Structural model is a simplified architectural model without losing any main feature (such as beams, columns, and their connection nodes) in the architectural model, information in architectural models could also support further structural analysis. But there are usually information missing or information inconsistency problems when an architectural model is exchanged with its counterpart structural model (Ren et al. 2018; Aldegeily et al. 2018).

To address this BIM interoperability problem, building information models (BIMs) need to be checked. Due to the large amount of information in BIM, a manual checking of the model would be labor intensive and time-consuming. The parameter-oriented and object-oriented nature of BIMs makes an automated information checking process feasible (Gross 1996). Different methods have been developed and used in checking BIMs for various purposes, such as for checking compliance with building codes (Choi and Kim 2008; Jeong and Lee 2009; Zhang and El-Gohary 2017), checking compliance with safety regulations (Zhang et al. 2011, 2013; Wang et al. 2015; Sulankivi et al. 2013), checking compliance with evacuation regulations (Choi and Kim 2014), and checking as-designed intent with as-built conditions (O’Keeffe et al. 2017). There are also commercial tools developed to help check BIM with predefined rulesets. Conceptually, Hjelseth and Nisbet (2010) defined model checking to be “execution of predefined rules on a building information model. Rules can be based on laws, regulations, codes, standards, advisory material or self defined requirements for generally or project specific use.” In the state of the art of automated BIM checking, the generation of rulesets cannot be fully automated with a perfect performance. Therefore the existing systems and methods only focus on checking BIM in a specific aspect. On BIM information completeness checking, model view definition (MVD)-based method is popular. For example, Lee et al. (2016) created an MVD-based BIM validation process and implemented a modularized validation platform to evaluate the information completeness of an industry foundation foundations (IFC) model using MVD rules.

In align with the BIM checking idea, the authors proposed to develop a BIM information checking method for structural analysis, to solve a problem they met in a previous experiment. In the previous experiment of exploring the interoperability between architectural and structural models, the authors selected a 12-storey building frame model and manually set the variables for external loads, section parameters, and material information in a structural software. However, the structural analysis results stayed unchanged regardless of material information setting changes. The structural analysis results are shown in Table 1 below. The authors converted the 12-storey building frame model to IFC format, IFC format is an open and neutral data format for building and construction data representation, which is widely used in the AEC domain. Structural analysis was conducted on the same IFC model in five different analysis scenarios. Von Mises stress, axial force, and torsion structural analysis results were obtained from these structural analysis experiments. Across these five analysis scenarios, cross-sectional properties, degrees of freedom, and external load information remained unchanged, the only variable was the material information. In Scenario 1, Steel ASTM A992 was chosen from the steel material panel as the material information input for the model. In Scenario 2, no material information was manually chosen, i.e., the use of default material was expected. In Scenario 3, 4,000 Psi concrete was chosen from the concrete material panel as the material information input. In Scenario 4, A615Gr60 rebar was chosen from the rebar material panel as the material information input. In Scenario 5, Steel ASTM A992 was chosen from the concrete material panel (to cover a wide variety of possibilities) as the material information input. However, all structural analysis results remained unchanged when using different material settings in these five scenarios.

**Table 1. Structural analysis results of five scenarios.**

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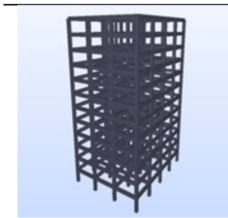
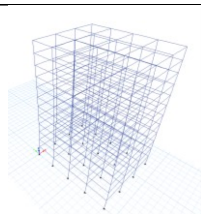
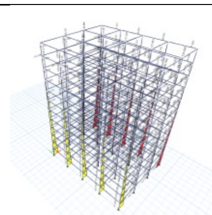
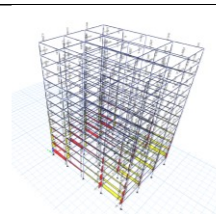
| Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 | Scenario 5 |
|---|---|---|---|---|
| Material property: Steel ASTM A992 (steel) | Material property: use default (A992Fy50) | Material property: 4000Psi (concrete) | Material property: A615Gr60 (rebar) | Material property: Steel ASTM A992 (concrete), |
|  Original model |  Structural analysis Von Mises stress distribution result |  Structural analysis Axial Force distribution result |  Structural analysis Torsion distribution result | All types of structural analysis results were the same regardless of material information setting changes |

An error analysis revealed that the material information was missing from the IFC files used in the structural analysis software. Such missing information between different software or file formats led to erroneous structural analysis results. To address this issue, the authors developed a BIM information checking method to check model information for use in structural analysis.

## PROPOSED INFORMATION CHECKING METHOD

The proposed BIM information checking method includes three main steps (Figure 1): Step (1) - Convert BIMs to IFC format. In this step, different types of BIM data are converted into IFC format. The IFC file will be used as the source of data. Step (2) - Apply information checking algorithm. In this step, the IFC data are checked by our developed information checking algorithm, corresponding to the application context of the IFC data. For example, structural analysis context requires material information and cross-sectional information of the structural components, among others. Architectural model requires material information, color and texture information, among others. Material information is required in many different application contexts. Different types of materials will have different parameter requirements. For example, wood material requires viscoelasticity information whereas steel material requires thermal expansion coefficient. Such required information will be used in the information checking algorithm developed in this method. In parallel to information checking using our algorithm, the IFC data will also be checked manually and using a MVD, respectively. Step (3) – Validate information checking results. In this step, the model information checking results from Step (2) will be validated in two ways: firstly, cross-compare the results between our information checking algorithm, the manual approach, and the MVD-based checking; secondly, conduct structural analysis on the IFC model and validate the information checking results through analyzing the structural analysis results.

Information checking is an important preprocessing step to prepare BIM data for use in analytical BIM applications. This proposed model information checking method supports such preprocessing of BIM. In addition, it indirectly supports the extraction of information from IFC (by verifying if the information exists in the first place) and therefore the mapping and

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transformation of IFC data into other types of data used in different application scenarios. Such mapping and transformation is essential for IFC-based BIM interoperability with software that do not support IFC importation. However, the information mapping and transformation is out of the scope of this paper and will be discussed in future research.

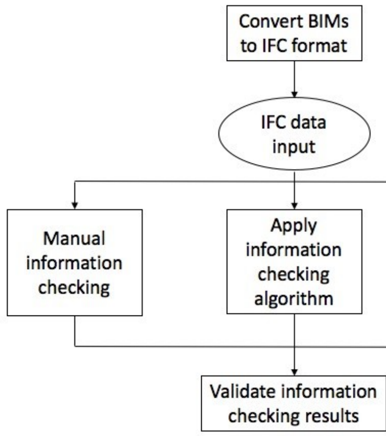


**Figure 1. Proposed model information checking method.**

## ALGORITHM DEVELOPMENT FOR IFC MODEL CHECKING

IFC data include many types of information such as material information and geometric information. Based on the structural analysis results shown in Table 1 and information requirements for structural analysis, the authors developed an information checking algorithm for material information (Figure 2). Material information was selected because of its variety and importance in a model for structural analysis. Specifically, material types, mass density, Poisson ratio, shear modulus, thermal expansion coefficient, compressive strength, and Young's modulus were included.

The developed IFC-based BIM information checking algorithm focuses on checking concrete and steel structures and runs as follows (Figure 2): Read IFC model and search for "Steel" keyword in the IFC file in order to determine if the material type of the model is "Steel." If so, print out "Material type: Steel", if not, search for "Concrete" keyword in the file. If found, print out "Material type: Concrete", if not found, print out "Neither steel nor concrete" and exit the program. After material type is detected, all "IfcPropertySingleValue" entity instances are extracted from the IFC model and stored in an intermediate file. The intermediate file will then be iterated through to search for each required parameter value in different types of materials. Different types of materials have different required parameters to be checked. For steel material, seven required parameters are checked in the algorithm: *MassDensity, PoissonRatio, ShearModulus, ThermalExpansionCoefficient, UltimateStress, YieldStress,* and *YoungsModulus*. For concrete material, six required parameters are checked in the algorithm: *MassDensity, PoissonRatio, ShearModulus, ThermalExpansionCoefficient, CompressiveStrength,* and *YoungsModulus*. This algorithm will end after all required parameters are checked. The results regarding what material information exists/not exists will be printed out in a report. Through this developed information checking algorithm, the missing material information during model

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importing/exporting process between different software can be found and listed.

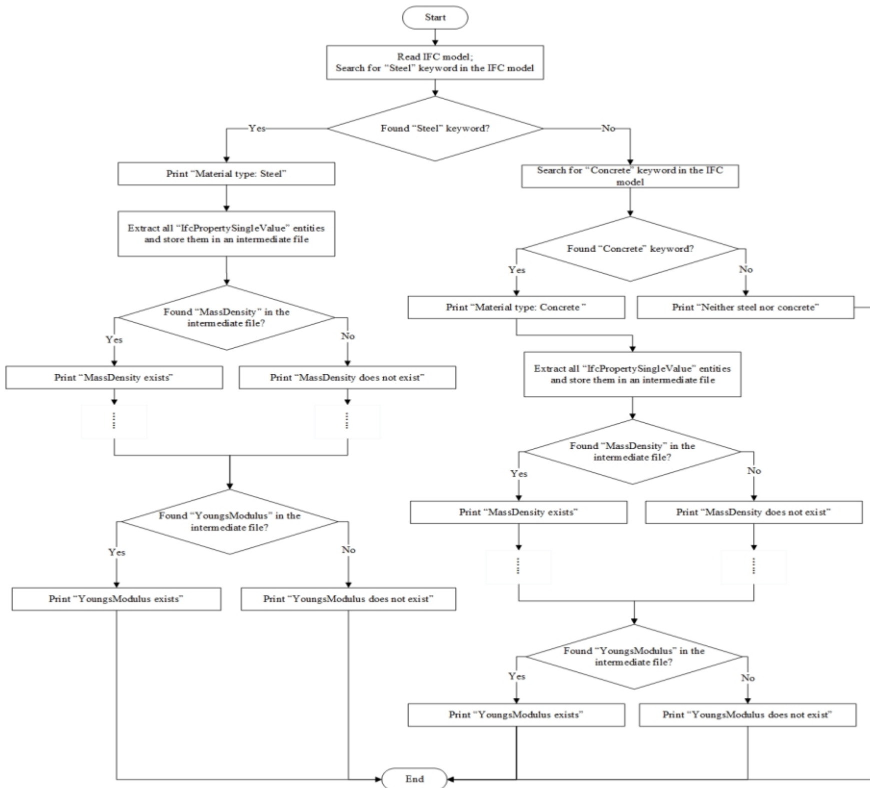

**Figure 2. Developed information checking algorithm.**

## INFORMATION CHECKING SYSTEM ANALYSIS

To support the automated IFC-based BIM information checking process, the authors conducted an information checking system analysis and proposed a new information, model, application, and application context (IMAAC) system model (Figure 3), which can be used to explain the BIM information checking process. The system model includes four different implementation levels: information level, model level, application level, and application context level. The information level provides information analysis requirements for the checking process. The checking of such requirements will be performed manually or implemented in programming languages to enable an automated check. The model level contains the original building models (usually an architectural model), which serves as a bridge between the information level and the application context level. The application level indicates the BIM software for a specific application, such as structural analysis, which may require model conversion between different file formats. The application context level defines the application or task to perform, which is the ultimate goal of and therefore can be used to verify the BIM information checking process. The four levels are interconnected (Figure 3). For example, software programs at the application level process information that have been checked using analysis requirements at the information level. The analysis requirements at the information level can be abstracted from the building models at the model level. The AEC application at the application context level provides contextual guidance for model analysis at the

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model level. At the model level, a building model could be created using information derived from the information level. To match the input format required by different BIM tools at the application level, the building models at the model level may need to be transformed. The AEC application context provides context and a test ground for the BIM tools at the application level. The BIM tools at the application level implement functions for use in the AEC application context.

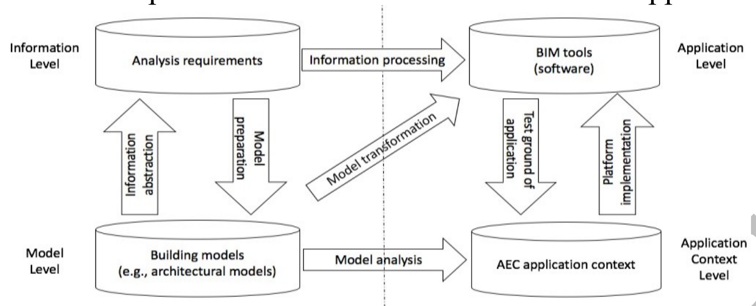


**Figure 3. Model information checking system model.**

In the context of material information checking for structural analysis in this paper, at the information level, different information checking requirements were used to develop the information checking algorithm (Figure 2). For example, for steel material, "UltimateStress", "YieldStress" were checked throughout the "IfcPropertySingleValue" instances of the intermediate file. In contrast, for concrete material, these two parameters were not required thus not checked. At the model level, an architectural model was created using material information requirements at the information level. At the application level, an IFC-compatible BIM tool for structural analysis was used to create a structural model based on the architectural model that was developed at the model level. The structural model preserved the main information for structural analysis such as frames and connection nodes from the architectural model. At the application context level, structural analysis was used to test information missing problems in the IFC model, because missing information could lead to erroneous structural analysis results.

## EXPERIMENTAL RESULTS AND ANALYSIS

To evaluate the proposed method, the authors created a frame structure (consisted of four beams and four columns) model in a BIM authoring tool, and comparatively conducted the material information checking to support structural analysis using the following three methods. In Method (1), information checking of the model was manually performed by direct observation of the IFC data in a text editor and manually analyzing the information. In Method (2), an MVD was developed and used to perform information checking automatically. In Method (3), a program was developed using Python programming language that implemented the information checking algorithm, which was then used to perform the information checking automatically. Before the checking, static loads were applied to the model and four points on the ground were fixed as boundary conditions. At the end of the information checking process using all three methods, the authors conducted structural analysis on the model in order to test the model checking results in terms of completeness. Any information missing would cause the structural analysis results to be empty or erroneous. A comparison of information checking results using the three methods are shown in Table 2.

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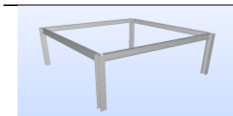
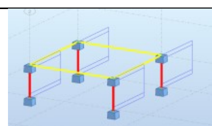
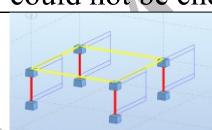
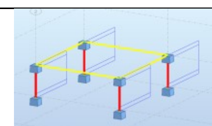
From the time efficiency perspective, manual information checking depends on the experience and expertise of users. It is a time-consuming and work intensive method. MVD-based information checking and the proposed method were more efficient than the manual checking method. In addition, the proposed method also outperformed the MVD-based method. From the accuracy point of view, the proposed method had the highest accuracy (100%), the accuracy of MVD-based proposed information checking method could also achieve 100%, but there were limitations in terms of checking scope. For example, "IfcExtendedMaterialProperties" could not be checked using MVD tools directly. Manual method had the lowest accuracy, which was around 70%~80%.

**Table 2. Information checking results.**

|  | 1) Manual checking | 2) MVD-based checking | 3) Proposed method |
|---|---|---|---|
| Time | 15 min | 10 min | 4 min |
| Facility/tool | File editor | MVD tools | Text editor |
| Accuracy | 70~80% | 100%<br>But certain entities such as "IfcExtendedMaterialPRoperties" could not be checked | 100% |
| Analysis verification results |  |  |  |

## CONCLUSION

Missing information during model importation and exportation between different software is an essential problem in BIM use, which needs to be fixed to enable BIM interoperability in the AEC domain. To help address this issue, the authors developed a model information checking method which uses customized computer algorithms to check required information in an IFC-based BIM. An experimental testing of the proposed method on a frame structure was conducted. The model information checking results using the algorithm were compared with a manual information checking method and an MVD-based information checking method. The results showed that manual information checking method was labor intensive, time-consuming and had lower accuracy than MVD-based method and proposed information checking method. The proposed method had the highest accuracy among the three information checking methods, because the checking algorithm was customarily created. While the MVD-based method had comparable accuracy with the proposed method, there were limitations in terms of checking scope. The proposed information checking method is expected to support BIM interoperability by helping people identify missing information from IFC-based BIMs.

## LIMINATIONS AND FUTURE WORK

Two main limitations of this paper are acknowledged: (1) this preliminary experiment was focused on material information checking only. In future work, the authors plan to incorporate the checking of more types of information, such as geometric information, load information, and cross-sectional information. (2) Only structural models were checked using the proposed method in this paper. In future work, the authors plan to use the proposed information checking method to check information in other types of models such as architectural models and management models.

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