# EVALUATION OF INDUSTRY FOUNDATION CLASSES FOR PRACTICAL BUILDING INFORMATION MODELING INTEROPERABILITY

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## ABSTRACT

The AEC (Architecture, Engineering, Construction) industry is an information intensive industry and all related processes employed during different phases of a project, including planning, designing, building, manufacturing, occupying, and maintenance, involve vast amounts of data that is used for a wide variety of purposes. Building Information Modeling (BIM) is a powerful shared knowledge resource which stores this data to support decision making about a facility through all these different phases in its life cycle. Nowadays, BIM is mostly used in the design and construction phases while it can also be highly beneficial beyond those stages. For example, in the Operation and Maintenance (O&M) phase, BIM could be used for automated facilities management or robotic inspection to provide semantic knowledge for navigation. For any implementation not related to the original intent of the BIM (design), organizations need to be able to represent their project data in a common interpretable form, which provides the possibility of an accurate exchange of data among different software products and platforms, known as interoperability. This study has investigated the current state of interoperability between software products used as Building Information Modeling tools. The main focus has been on a popularly used format for BIM models, Industry Foundation Classes (IFC), since it has been specifically developed to enable standardized data exchange. The research methodology involved a comprehensive literature review and the gathering of all fragmented prior research related to the field in order to develop a consistent understanding of the current state of knowledge. This was accompanied with a detailed case study that evaluated and compared two dominant pieces of BIM software, Revit and Bentley, and examined their interoperability strengths and weaknesses while using the IFC format.

## KEYWORDS

Building Information Modeling, Interoperability, Industry Foundation Classes

## INTRODUCTION

### Building Information Modeling (BIM)

The National BIM Standard Project Committee defines a Building Information Model as “a digital representation of physical and functional characteristics of a facility and a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition” (NBIM, 2007). This data source contains characteristics of a structure composed of ‘intelligent objects’ rather than simple lines, arcs, and text. It provides a way to share project data throughout the lifecycle of a building. This data can include conceptual design data, geospatial information, financial data, mechanical, electrical and plumbing layout, energy analysis results, and other types of information used by the project team.

BIM technology is receiving great attention in the architecture, engineering and construction (AEC) industry, and since it contains a complete set of information of the lifecycle of a structure in the form of a digital model, it is widely projected to be the technology of tomorrow. By being a comprehensive digital database, it is rapidly gaining acceptance as the preferred method of communicating the design professional's intent to the owner and project builders. The valuable BIM models can also be used by any other member of the design team to coordinate the structure's mechanical and electrical systems and identify interferences. Furthermore, the contractor team can use it for preparing fabrication drawings, ordering materials, scheduling construction process, and planning erection sequences. BIM has been traditionally used for design and its use in the construction phase has also been increasing recently. However, nowadays owners have realized the potential of BIM and insist on inheriting the BIM models for further use. The owner can benefit from the BIM model as an archive of as-built information, for purposes such as Facility Management (FM) decision making tool or repository of materials.

This paper argues the importance of using BIM in different phases and emphasizes on its use in stages other than design and construction. The authors propose Figure 1, which illustrates the potential uses of BIM in different phases of any constructed project during its life cycle. The bold text in Figure 1 indicates the new potential areas and applications that the authors believe BIM can be highly beneficial in and are currently working on. These include the use of as-built BIM to facilitate decision making for facility management purposes, as well as integration of BIM with Human Motion Modeling (HMM) studies to implement ergonomics concepts, evaluate constructability, and improve safety. Robot localization and mapping, as one of the major keys to facilitate use of robots in construction, is also another potential area where BIM can be highly beneficial. Focus on these emerging applications of the BIM technology, will highly improve the state of visualization in the construction industry. However, for BIM to be used for purposes outside its native application, such as those mentioned above, transferring the information rich model and all its attributes is essential. This transfer of information without loss of data is called interoperability and is the key to completely realizing benefits of BIM as envisioned in Figure 1. Therefor this paper investigates the current state of interoperability between software products used as BIM tools.

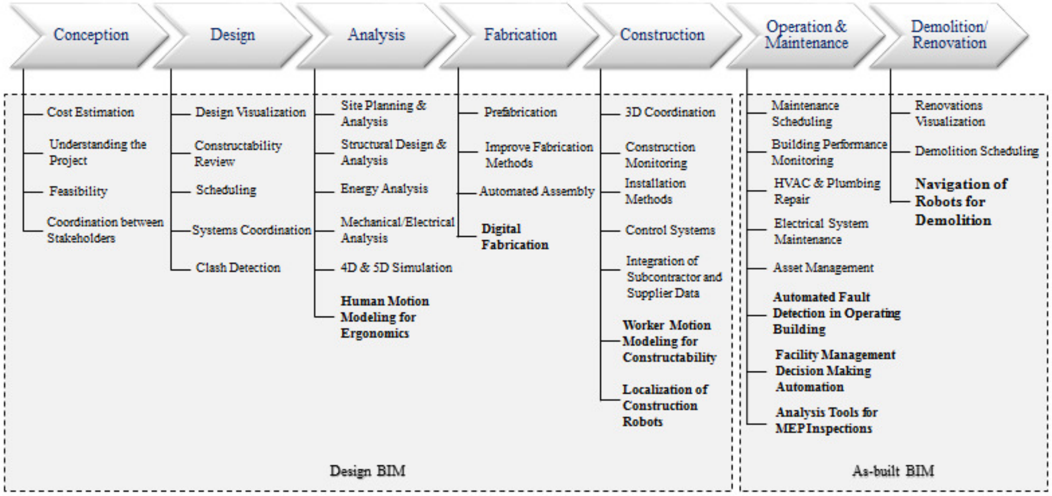


Figure 1- Potential Applications of BIM in different Phases of a Constructed Project

As shown in Figure 1, there are many benefits in converting to a BIM-based work process. As discussed, currently researchers focus mostly on development and use of BIM in the design and construction phase of a project, concentrating on: Use of BIM for design (Eastman et al., 2008; Khemlani, 2009; Khanzode et al., 2008), application of knowledge-based BIM (Motawa et al., 2012; Hwang et al., 2010; Singh et al., 2011; Tatum et al., 2000), maintainability and clash detection (Eastman et al., 2008; Leite et al., 2009; Dunston et al., 1999), use of BIM in energy analysis and sustainability (Cho et al., 2010; Stumpf et al., 2009; Barnes, 2009; Miller, 2010), and development and accuracy of as-built BIM (Tang, 2010; Leite, 2012; Liu, 2012; Akinci, 2011). Potential benefits of implementing BIM knowledge in the operation and maintenance phase is widely accepted among researchers, and related research indicates great interest in the industry to gain advantage of new and unique opportunities that as-built BIM offers (Becerik-Gerber, 2012).

## Interoperability

Architecture, engineering, construction, and facilities management are information intensive industries, and are highly dependent upon effective information technologies. Various software and tools are used to help with the AEC/FM design and management tasks. However, currently the information is passed from one project member to the next by producing paper-based or electronic documents which can only be interpreted by people. These members must also re-enter relevant information into their own professional tool. This manual data entry is a non-value adding activity, can often introduce errors into the project, and inhibits the use of better computational tools (Froese, 2003). To address this problem of information communication and exchange, the topic of interoperability has been taken up as one of the primary areas for research and development in Information Technology (IT) for AEC/FM.

Interoperability can be simply defined as the ability of two or more systems or components to exchange information and to use the information that has been exchanged. With respect to software, the term interoperability is used to describe the capability of different programs to exchange data via a common set of exchange formats, to read and write the same file formats, and to use the same protocols. Sharing building data without any loss of information is necessary for BIM's success in any project. Software developers are trying to enable information interchange among the various software programs employed by project team members during the design and construction process.

Interoperability between various software applications can be achieved in a number of ways such as: Using software that directly reads the proprietary file format contained in the BIM software application, which will be the case for a suite of software applications developed by one software vendor; using software that incorporates an Application Programming Interface (API), providing a well-developed interface between software from different providers; and using software that supports data exchange standards such as Industry Foundation Classes (IFC) format (Gayer, 2009).

The National Institute of Standards and Technology (NIST) has described the cost burden to the U.S. construction industry due to inadequate interoperability among computer-aided design, engineering, and software systems in a recent study. They have identified an additional cost of 15.8 billion dollars annually for the stakeholders (Gallaher et al., 2004), but most in the industry feel that this number is significantly higher as the business opportunity of improved interoperability was not included. Time spent on overcoming non-interoperability is the primary driver of costs. A McGraw-Hill Construction survey (McGraw-Hill, 2007) showed that manually re-entering data from application to application ranks the highest at 69% with 75% of engineers reporting it as a primary cost. Time spent using duplicate software (56%) and time lost to document version checking (46%) are also key cost drivers. Another McGraw-Hill Construction survey also showed that ‘improved interoperability’ ranks among the factors that have the greatest influence on the decision to use BIM in the industry (41%). Other factors included owners demanding it (49%), BIM’s ability to improve communicating among the build team (47%), and the opportunity to reduce construction costs (43%).

### Industry Foundation Classes (IFC)

Software interoperability in the AEC industry has been developed and promoted by the International Alliance for Interoperability (IAI) since 1995. The Industry Foundation Classes (IFC) format developed by IAI is the means of achieving interoperability. It can be described as a general object-oriented data model of buildings that facilitates the sharing and exchange of information among IFC-compatible software applications (IAI, 1999). IAI regularly publishes new releases of the IFC object model. Each of these new model releases contain new classes and schemata that enable improved interoperability among new software applications and upgrades of common software products in the AEC industry.

The IFC format models all types of AEC/FM project information, from tangible components such as walls, doors, beams, slabs, to abstract concepts such as space, geometry, and material. It also includes project costs, schedules, and organizations. The difference between ‘intelligent objects’ in IFC and blocks or objects in 2D CAD software is that the IFCs are by definition 3D and reside in an integrated model that composes the virtual building. Instead of working with 2D entities such as line, arc, and text, the user works with the objects directly, using their familiar names, such as wall, slab, roof, and building.

The information from almost any type of computer application that works with structured data about AEC building projects can be mapped into IFC data files. In this way, IFC data files provide a neutral file format that enable AEC/FM applications and software to efficiently share and exchange project information. However, the IFC object model cannot provide interoperability by itself; software developers must make their software ‘IFC-certified’. So in order to achieve appropriate interoperability, having IFC-compatible software that is useful to the industry is essential.

From the point of view of the basic technical ability to exchange AEC/FM information, IFCs have now been accepted as a viable interoperability technology. Significant portions of the IFCs are now mature, stable standards and numerous prototype and early commercial systems have demonstrated their extensive information exchange capabilities. However, the IFCs are still in an early stage of development, since it is not clear when the users will be confident about IFC interoperability, i.e. sharing of data without any loss of information. Researchers are continuously working on exploring weaknesses of IFC and its development to serve in different applications in the industry, such as structural analysis, energy simulation, etc.

## CASE STUDY

As a case study to examine potential interoperability weaknesses of the IFC format, two of the most common BIM software products, Autodesk Revit and Bentley, have been evaluated. A BIM model of the G.G. Brown building at the University of Michigan was created using Autodesk Revit. The goal of this case study was to examine the interoperability in two different releases of the same software, Revit 2012 and Revit 2011, and also interoperability among these two main BIM software used in the AEC/FM industry.

Figure 2 shows the model built in Revit Architecture 2012. To examine the basic interoperability issues, the model only includes architecture elements and does not contain mechanical, electrical, or plumbing elements.

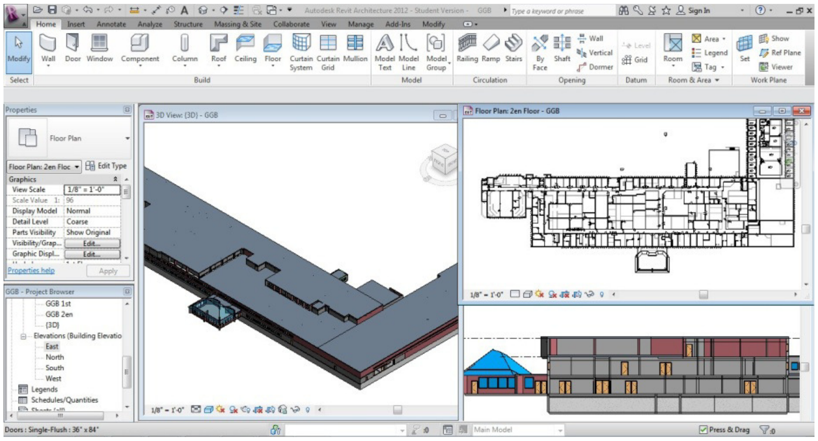
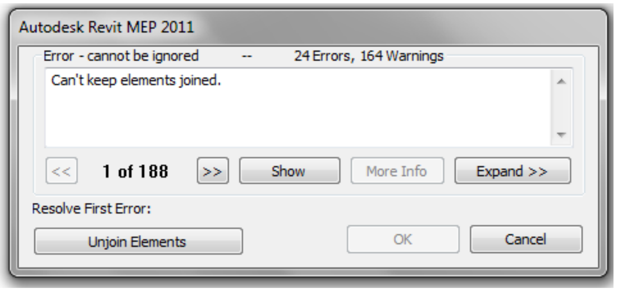


Figure 2- 3D View and Section Views of the G.G. Brown Building in Autodesk Revit 2012

The skin model was then exported to IFC from Autodesk Revit 2012 and imported into Autodesk Revit 2011. After importing the IFC file, an error window appears mentioning the number of errors in importing the IFC file and a description of each, such as: one element is completely inside another; can't make wall; can't keep elements joined, etc. (Figure 3).


Autodesk Revit MEP 2011

Error - cannot be ignored -- 24 Errors, 164 Warnings

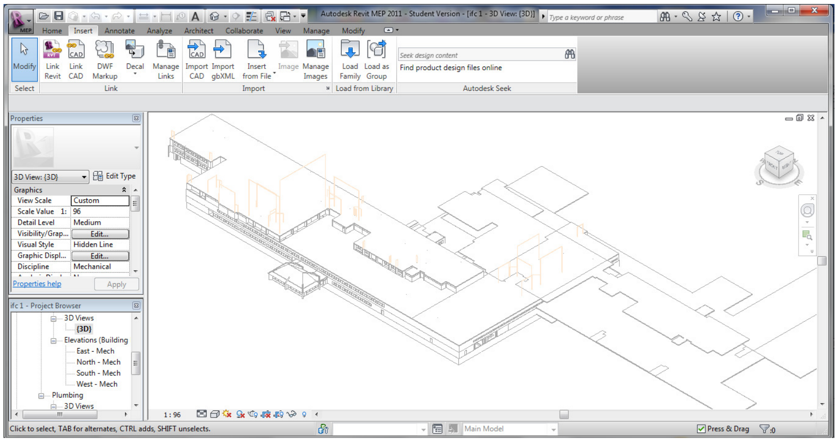
Can't keep elements joined.

1 of 188

Resolve First Error:

Figure 3- Error window appearing after importing IFC file to Revit 2011

Reporting the errors of importing the IFC file is one of the strengths of Revit. However, the number of errors is too high, and the imported model is not reliable. Figure 4 shows the imported model in Autodesk Revit 2011, where the elements have lost their attributes and no longer hold the properties assigned to them in the original model.



3D View: {3D}

View Scale: Custom
Scale Value 1: 96
Detail Level: Medium
Visibility/Grap...: Edit...
Visual Style: Hidden Line
Graphic Displ...: Edit...
Discipline: Mechanical

Click to select, TAB for alternates, CTRL adds, SHIFT unselects.

Figure 4- BIM model after importing IFC file to Autodesk Revit 2011

The same IFC file exported from Revit 2012 was then imported to Bentley Microstation V8i. The software does not report the errors, but at a closer look it is evident that a noticeable amount of the element properties are lost and some elements are missing.

## DISCUSSION

The process of exporting a model to IFC and importing it into the same or any other IFC–complaint application without loss of data is called round tripping. This case study and similar experiences indicate that applications that can round trip IFC data provide an export switch to store proprietary application data in a container. However, such IFC-files can only be used by the same application and, as showed in this case study, possibly only by the same version. The IFC specification does not cover export of certain proprietary data types that support application functions. As these cannot be exported, an IFC round tripped file cannot create the original application data, thus certain features will no longer work.

For standard simple objects such as walls, beams, columns and doors, the parametric shape will be exchanged in round tripping without much problem. However, properties for complex IFC entities, such as curtain walls, stairs, or even more complex slabs or walls, are not transferred because applications have different proprietary methods to create such entities with parameters, rules, and constraints. To export these objects to a format that other applications could support would be a considerable development in interoperability of BIM models.

Furthermore, the usual IFC coordination view is a vendor-neutral consensus BIM schema that supports coordination across a wide range of proprietary vendor formats. Therefore, its specification does not cover or allow for ‘native’ application-specific object definitions. This means that when importing IFC, the software must try to interpret and transform imported objects to their native objects as best as possible. Since a complete one-to-one match is usually not possible, imported elements differ from natively created elements to some extent (Thein, 2011).

The authors examined the interoperability abilities of Bentley Microstation and Autodesk Revit in this research. Similar experiences have been carried out by others researchers focusing on other software and applications. Autodesk Revit does not provide the option to downgrade a project, i.e. the ability to save a version backwards to a previous version. The reason is that Revit changes extensively with each version, adding elements and parameters that not only add functionality, but form connections with existing Revit elements that have been upgraded from previous versions. While it might be possible in some cases to downgrade a new element into a previous version of Revit, at best it would arrive in the previous version as dead geometry. All of its behavior would be dependent on the more recent version of Revit. All behavioral relationships established to other elements in the model would also be broken, resulting in unpredictable cascading behavior which would likely then compromise the integrity of the model (Autodesk, 2011). When an IFC file is imported to Autodesk Revit, the elements are exchanged as generic models, which are in-place objects. These imported elements that might be floors, walls, columns, beams etc. should be in FLOORS, WALLS, COLUMNS, BEAMS families instead of the IN-PLACE family.

The argument over whether the source of interoperability issues is the software or the standards is still inconclusive. Are software developers catching-up with the developments in the standards? Active participation of the software vendors in the standardization process will certainly improve the status of interoperability in the industry. However, the question is how willing are they to make their software hundred percent interoperable? As an exchange format, IFC is only concerned with results of application functions, not how they have been obtained or produced. Software vendors would be opposed to exporting semantic data that exposes proprietary information and trade secrets (Thein, 2011).

Software vendors should continue their effort in certifying their latest versions of software and buildingSMART as the standardization organization should improve the IFC certification process. Currently software developers eagerly get their applications to be IFC-certified to achieve more acceptance in the market by claiming their software to be IFC-compatible. However, being IFC-certified does not mean an application can import and export IFC format without loss of data, since the IAI certifying process involves satisfying some minimum requirements and not fulfilling the requirement of no-loss-interoperability.

This research does not look into specific solutions to encountered interoperability issues and focuses on the broader view. Some researchers (Pniewski, 2011) have worked on such short term solutions and have presented some practical methods to reduce the loss of data. As an example, separating elements of the model has been found an effective way of reducing issues of the displaced geometry of individual objects. Splitting the models into components needs to be considered in light of parametric nature of objects, which frequently would translate more effectively in isolation.

## CONCLUSION

Despite all the current issues with interoperability, a BIM-based work process in projects is highly recommended. Interoperability, even in its current limited form, results in great degree of process improvement. But interoperability issues will continue to limit users' ability to freely exchange data between software packages. No-loss-interoperability is dependent on the further development of a strong industry standard, and software vendors' incorporation of this standard into their products.

Interoperability affects entire the AEC industry, involving the build teams who utilize a wide variety of specialized software applications and share the data among the interdisciplinary teams. The industry sees the software incompatibility issues as a key factor hampering the build teams' ability to share information. Deficiencies in interoperability affect workflows and have direct impact on project program/schedule and budgets. The excess cost and program/schedule implications are mostly caused by manual re-entry of data from application to application, therefore duplicating the tasks by project members. The costs are also accrued by using duplicate software and the time lost due to document version checking and ineffective processing of information. Similarly, based on surveys and using estimates of past, current and future usage of BIM, the interoperability issue of McGraw Hill Construction SmartMarket Report states that on average, 3.1% of project costs incurred by clients, designers and contractors are related to software non-interoperability (McGraw-Hill, 2007). In addition, interoperability of BIM software applications greatly impact projects' quality assurance, and most importantly affects customer satisfaction (Pniewski, 2011).

The key factor causing interoperability issues is the continually advancing and complex nature of AEC projects today, the volume of specialist disciplines involved, and the software solutions employed. These days are still early days for implementation of BIM and the technologies it offers. This is deepened by companies' diversified management approaches and the wide range of processes they use. Blending the above with benefits of interdisciplinary collaborative approach, companies are left with evolving technology and the need for improving it. Related research documents that there is no single factor causing interoperability issues among BIM software applications; instead, there are numerous factors in place. These factors, although examined only partially, can be used as a practical guide on how to remove the obstacles in an attempt to increase the chance of achieving interoperable BIM in collaborative AEC projects.

A successful project should begin with establishing a well-thought process and coordination workflow. Many software translators are not designed for multiple exchanges, and work only in one specified 'direction'. The software may convert the model well and export it, but then could return with corrupted files by merging the model back to its repository. Implementation of appropriate workflow-based translators needs to match the workflow requirements, and efforts are required to accurately define IFC Views for the project-specific workflows (Eastman et al., 2008). This should follow with an examination of the process flow diagrams and verification of these with the software functionality through testing. Only after solving these basic issues regarding interoperability the vision proposed in Figure 1 can be realized and BIM can be widely used in all the different areas mentioned without any impediments.

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