Interoperability Issues between Different BIM Software Products

Case Study: G. G. Brown Building, University of Michigan

By

Alireza Golabchi and Vineet R. Kamat

UMCEE Report No 2012 - 02
Civil and Environmental Engineering Department
UNIVERSITY OF MICHIGAN
Ann Arbor, Michigan
April 2012

Copyright 2012 by Alireza Golabchi and Vineet R. Kamat
Acknowledgements

I would like to express my deepest gratitude to my supervisor, Professor Vineet R. Kamat, who has supported me throughout my thesis with his patience and knowledge while allowing me the room to work in my own way. I attribute the level of my Master’s degree to his encouragement and effort and without him this report, too, would not have been completed or written. One simply could not wish for a better or friendlier supervisor.

I also wish to express my love and gratitude to my beloved family; for their understanding and endless love, through the duration of my studies.

Lastly, I offer my regards and blessings to my friends and all of those who supported me in any respect during the completion of this research.
Abstract

The AEC (Architecture, Engineering, Construction) industry and the related processes employed during planning, designing, building, manufacturing, occupying, and maintenance of facilities all involve data that is used for a wide variety of purposes during the project life cycle. With the complex nature of AEC projects today, these processes engage multiple organizations and numerous stakeholders, such as interdisciplinary professionals, often spread around the world, utilizing specialized and diversified computer applications and systems. In order to effectively support the use of information, 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. This study has investigated current state of interoperability between software products used in Building Information Modeling (BIM). Key attention was paid to the most commonly used format for BIM models, Industry Foundation Classes (IFC). The methodology to investigate the research problem in this report involved literature review and gathering of all scattered prior research related to the field, in order to have them as a consistent piece of information altogether, and also experiencing a case study on two of the dominant BIM pieces of software, Revit and Bentley, and examining their interoperability strengths in using IFC files.

Keywords: Building Information Modeling, Interoperability, Industry Foundation Classes
# Table of Contents

1. Building Information Modeling (BIM) 1  
   1.1 Introduction 1  
   1.2 Information Transfer in BIM 5  

2. Interoperability 7  
   2.1 Introduction 7  
   2.2 Impediments to Interoperability 10  

3. Industry Foundation Classes (IFC) File Formats 14  
   3.1 Introduction 14  
   3.2 IFC and Interoperability 16  
   3.3 IFC Limitations 18  

4. BIM Software Products 19  
   4.1 Autodesk Revit Architecture 19  
   4.2 Bentley 21  

5. Case Study: 3D model of G. G. Brown Building 22  

6. Interoperability Issues Using Revit and Bentley 28  
   6.1 IFC File Issues Using Revit 28  
   6.2 IFC File Issues Using Bentley 31  
   6.3 Quick Comparison between Revit and Bentley 33  

7. Conclusion 34  
   7.1 Future of BIM and Interoperability 34  
   7.2 Future Work 35  
   7.3 Possible Scenarios 36  
   7.4 Conclusions 37  

8. References 39
1. Building Information Modeling (BIM)

1.1 Introduction

One of the earliest definitions of BIM was introduced by Prof Charles Eastman at the Georgia Institute of technology whose theory is based on the view that the term ‘building information model’ is the same as a ‘building product model’.

Building information modeling integrates all of the geometric model information, the functional requirements and capabilities, and piece behavior information into a single interrelated description of a building project over its lifecycle. It also includes process information dealing with construction schedules and fabrication processes (Eastman 1999).

Companies such as Autodesk define BIM as a building design technology that is characterized by the creation and use of coordinated, internally consistent, computable information about a building project in design and construction. Others such as Bentley describe it as a modeling of both graphical and non-graphical aspect of the entire building life cycle in a federated database management system. A more comprehensive definition of BIM, defined by the US General Services Administration (GSA) is as follows:

Building Information Modeling is the development and use of a multi-faceted computer software data model to not only document a building design, but to simulate the construction and operation of a new capital facility or a recapitalized (modernized) facility. The resulting Building Information Model is a data-rich, object-based, intelligent and parametric digital representation of the facility, from which views appropriate to various users’ needs can be extracted and analyzed to generate feedback and improvement of the facility design.
In summary,

- BIM is a model based technology linked with a database of information.
- It has a parametric change engine, which automatically coordinates changes made anywhere- in model views or drawing sheets, schedules, sections and plans.
- BIM increases the ability to control data and information in an interoperable format.
- It can be used with a variety of programs/functions such as cost estimations, simulations, scheduling, structural design, GIS integration, facilities management and energy analysis.

BIM technology is getting increasingly valuable in the architecture, engineering and construction (AEC) industry, and is being widely projected to be the technology of tomorrow. By virtue of its definition, it contains a complete set of information about the life cycle of a building in the form of a digital model. The information set could range from the building’s geometric data, to spatial relationships, geographic data, building components, manufacturer details, construction schedules, fabrication processes and so on; therefore, as a knowledge resource database, it is an extremely powerful tool. It is rapidly gaining acceptance as the preferred method of communicating the design professional’s intent to the owner and project builders (Kumar 2008). These data-rich models can be used by other members of the design team to coordinate a building’s various systems (such as electrical or mechanical systems) or identify interferences (Figure 2).

Figure 1: BIM’s presence in all phases of project (Smith 2007)
In addition, members of the build team can use these models as input for preparing fabrication drawings, ordering materials, developing construction schedules or preparing erection sequences. There is even software and hardware that will allow the site surveyor to interface the building column grid with GPS data, significantly automating the process of inspecting the construction site. The owner can use the model as an archive of as-built information, and a repository of materials, finishes, even equipment, contained in his building. Although five years ago the long-term viability of this new modeling method was uncertain and its rate of adoption unknown, it is now clear that Building Information Modeling represents the future of building and infrastructure design and construction management delivery. It is no longer a question of if BIM will be widely adopted, but when.

Figure 2: A BIM Project Flow Chart (Burt 2009)
Research and experience have shown many benefits in converting to a BIM-based work process, some of which are as follows:

- Increased productivity in document development
- Better coordination of in-house project documents
- Better communication between design team members
- Fewer RFI’s
- A faster, less labor-intensive shop drawing review process where paper approval drawings are virtually eliminated
- Maintaining leading-edge technical capabilities

Despite its increasingly widespread use across the design and construction spectrum, in some respects Building Information Modeling is still in an early developmental phase. Its inherent data-richness creates very large data files. This mass of data, combined with the large number of collaborators in the design and construction process, creates a jumble of data that must be classified and arranged for the information to be freely exchanged. The BIM community is likely only in the early stages of mastering this huge array of data, users and software (Burt 2009).
1.2 Information Transfer in BIM

A key to BIM’s adoption as the principal design delivery method is the ability of the various team members to easily share building data. Software developers are busily at work attempting to enable information interchange among the myriad of software programs employed by project team members during the design and construction process. As Andrew Gayer has explained (Gayer 2009), interoperability between various software applications can be achieved in a number of ways. Three of the most common are:

- Using software that directly reads the proprietary file format contained in the BIM software application. This may 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.
- Using software that supports data exchange standards having industry-wide acceptance. The steel industry’s CIMSteel Integration Standards (CIS/2) is an example of a successful application of a data exchange standard. The Industry Foundation Classes (IFC) are intended to provide a neutral model framework that will integrate a variety of design and construction management software into a Building Information Model. Work continues on developing a CIS/2 to IFC translator, which should greatly enhance data exchange within the steel segment of the BIM environment.

All of these methods of data exchange are currently being used, with varying degrees of success.

In building information models, the building model is exported as a data file, based on an open standard, which in turn can be imported by various modules. However, the absence of a dynamic data link means that changes in BIM may not be accurately and effectively reflected in the modules. As an example, Autodesk Revit is able to import and export the following formats:
Table 1: Importing and Exporting Formats in Revit

<table>
<thead>
<tr>
<th>Imports the following formats:</th>
<th>Exports the following formats:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Rvt, Rfa files</td>
<td>• Rvt and Rfa files</td>
</tr>
<tr>
<td>• ACAD dwg and dxf files</td>
<td>• CAD formats such as dwg and dxf files</td>
</tr>
<tr>
<td>• IFC formats</td>
<td>• ODBC database</td>
</tr>
<tr>
<td></td>
<td>• Image files such as jpegs</td>
</tr>
<tr>
<td></td>
<td>• gbXML files</td>
</tr>
<tr>
<td></td>
<td>• IFC formats.</td>
</tr>
</tbody>
</table>
2. Interoperability

2.1 Introduction

Architecture, engineering, construction, and facilities management (AEC/FM) are information intensive industries, and are increasingly dependent upon effective information technologies (IT). Various computer tools are used to support almost all AEC/FM design and management tasks, and the information entered into all of these tools describes the same physical project. However, this information is passed from one tool to the next by producing paper-based or electronic documents which can only be interpreted by people, who must re-enter relevant information into the next computer tool. This manual data re-interpretation and entry is a non-value adding activity, can often introduce errors into the project, and inhibits the use of better computational tools. 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 IT for AEC/FM. Interoperability—the ability for information to flow from one computer application to the next throughout the lifecycle of a project—relies on the development and use of common information structures throughout the AEC/FM industry (Froese 2003).

Interoperability is a property to the ability of diverse systems and organizations to work together (inter-operate). It can also 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.

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 their report ("Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry"). In addition, the Architectural/Engineering Productivity Committee of The Construction Users Roundtable (CURT), in analyzing why building owners regularly experience project schedule and cost overruns determined that the project delivery process is fraught by lack of cooperation and poor information sharing ("Collaboration,
Integrated Information and the Project Lifecycle in Building Design, Construction and Operation”).

The interoperability issues of the design/construct community are mirrored in the structural engineering profession. There are dozens of analysis and design (A&D) programs available for modeling various aspects of a structure. Most engineering firms have several of these tools at their disposal. In the course of a project’s design, engineers usually employ one or more of these modeling tools. However, the graphical representations of the engineer’s designs traditionally have been rendered in a CAD-based set of design drawings. These CAD drawings are usually created "from scratch" with very little interface with the three dimensional models created in the design process. In addition, there is usually little data embedded in an AutoCAD file that can be used by clients or other members of the design or construction teams. In other words, CAD drawings are little more than electronic versions of the manual drawings created in an earlier era (Pniewski 2011).

A significant process improvement can be achieved by integrating the models created for analyzing and designing a project with a Building Information Model that will be delivered to the client (either as an electronic file, or, more typically at this stage of BIM’s evolution, as a conventional set of two dimensional plans, sections and details). BIM software currently does not offer design or analytical capabilities; these are still the purview of A&D software such as RISA 3D, RAM Steel and SAP2000 and many others. In order for a single model to be created that will serve as the design tool and the deliverable, interface between A&D and BIM software is critical. The BIM software companies are developing these interface tools. However, due to the various BIM and A&D software in existence, and the fact that a standard format for interoperability such as IFC is still developing, many of these links are being developed on a proprietary basis between various software developers. Some engineering firms with the resources and expertise are creating their own API’s, though this option is not feasible for most firms.

Interoperability – as the sharing of information between these different BIM models – is critical to the success of BIM. Demanding support for open data standards and non-proprietary access to BIM data is an urgent priority for the industry if we are to avoid the inefficiencies and recurring inaccuracies of data re-entry. Interoperability will allow the reuse of project data which has
already been created and thus ensure consistency between each of these models as different representations of the same building. It will also allow the comparison and validation of purpose-built models in support of faster revision cycles and the iterative nature of the design process. Consistent and accurate data accessible on demand by the entire project team will contribute significantly to mitigating project schedule and cost over-runs (Burt 2009).

Figure 3 shows the interoperability cycle in AEC, where progress will be the result of collaboration between business practices, software technologies and interoperability standards.

Figure 3: Interoperability and AEC (Sullivan 2009)
2.2 Impediments to Interoperability

Though all major A&D software provides interoperability with one or more of the BIM software (Figure 4), the devil is in the details, and there are always many details involved in accurately rendering a complex, three-dimensional structural model in a collaborative environment.

In a BIM-based design delivery method, the first step in the modeling process is choosing the software in which to initiate modeling. Depending on the software, model migrations may work best when the model is initiated within either the BIM software or the A&D software. For the model to successfully migrate from BIM to A&D software or vice versa, careful attention must be paid to member work lines, member orientations, element definitions, and a host of other parameters. Even if the initial model is created with the greatest care, mistranslations occur that must be manually fixed in the subsequent model.

![Figure 4: Interoperability between Analysis & Design Software and BIM Software (Burt 2009)](image)

In the case where modeling is initiated using BIM software, once the building information model has reached an appropriate stage of development, it can be migrated to the A&D software. Design takes place, and the revised data is migrated from the A&D model back to the building
information model. Additional changes that take place after the creation of these dual models can require significant model maintenance, with repeated merges of the A&D and BIM models. Over time, this "round-tripping" of data from one model to another can lead to data loss and a loss of model accuracy. Oftentimes, the solution is to sever the link between BIM and A&D models prematurely, or perhaps abandon the process entirely, so that two models are developed and maintained, serving two disparate functions. This unfortunate result represents a missed opportunity for process improvements and productivity gains for the structural engineer struggling to justify the expense of BIM implementation.

Another issue which inhibits interoperability is version compatibility. New features are regularly incorporated into both A&D and BIM software, resulting in software upgrades on a seemingly continual basis. Particularly when the method of linking A&D software with BIM software is via an API, the link between last year’s version of your A&D software (that interfaced reasonably well with last year’s version of your BIM software) may not work at all with this year’s version. And even if you upgrade both your A&D and BIM software faithfully, the API that links the two new versions may not be developed until well after the version upgrades have been implemented (Howell and Batcheler 2010).

Another version compatibility issue may occur on long-term projects with numerous collaborators. If all the collaborators are not updating their software on a regular basis, those collaborators using obsolete software will likely be unable to read data created in newer versions. A common solution is for all collaborators to use the same version of their BIM software throughout the duration of a project. The result is that design firms will usually have more than one version of their BIM software, along with the compatible version of their A&D software, coexisting within their office. This is obviously not an ideal situation from an IT standpoint or from a training perspective.

Archiving projects is an even more serious concern. Backward compatibility may prove viable over several software version upgrades, but what is the likelihood that the BIM database will remain accessible to future generations of software over the life of the structure?

While interoperability is an important requirement for BIM-based projects, the goal of full interoperability is far from being realized, in the AEC sector. The NIST study mentioned before,
considered inefficiencies resulting from inadequate interoperability and includes manual reentry of data, duplication of business functions, and the continued reliance on paper-based information management systems. This study is an indication of the AEC industry’s inability to exploit ICT to realize its full benefits.

Although there is considerable effort in interoperability standards development, there still exists today a failure to deliver seamless AEC interoperability. The AEC sector perspective on interoperability, like that of many other industrial sectors, is reductionist and unable to fulfill the promise of an interoperable business environment. Indeed, the AEC sector’s efforts for interoperability have been very focused on data aspects of information systems. There is a need for AEC to extend the more technically focused notion of interoperability to cover the organizational and operational aspects of setting up and running ICT-supported relationships.

Indeed, interoperability is often discussed in the context of technical integration related to platforms, network devices and communication protocols, as well as syntactic and semantic data formats (Peristeras and Tarabanis 2006). This is reflected by the most cited definition of interoperability that characterizes interoperability as ‘the ability of two or more systems or components to exchange information and to use the information that has been exchanged’ (IEEE 1990). Over the last decade, internet and web service technologies have significantly fostered interoperability at the transport and communication level (Alonso et al. 2003).

But with the broader use of these technologies, a multitude of interoperability issues have to be solved at higher levels in order to allow for seamlessly integrated collaboration. Whereas many authors have underlined the need for aligning the semantics (Zhang 2004), some of them consider interoperability in the broader context of value chain integration.

Within the AEC sector there is a recognition of the need to address a context wider than just the technological issues of interoperability on BIM. This is the case of the Information Delivery Manual (IDM) of the IAI, which considers, in addition to the IFC’s standards, a methodology to support the implementation of BIM, addressing the business processes and information exchange requirements. IDM captures, and progressively integrates business processes whilst at the same time providing detailed specifications of the information that a user fulfilling a particular role would need to provide at a particular point within a project (IAI 2011). To further support the
user information exchange requirements specification, IDM also proposes a set of modular model functions that can be reused in the development of support for further user requirements. IDM describes a set of process maps, exchange requirements and functional parts, and has been recognized as the key feature that makes IFCs work. However, in spite of being a valuable development, it falls short of the broader needs regarding interoperability on issues such as intangibles, e.g., culture and values, or management of contractual relationships on project development.
3. Industry Foundation Classes (IFC) File Formats

3.1 Introduction

Software interoperability in the building industry (which also includes facilities management) has been developed and promoted by the International Alliance for Interoperability (IAI) since 1995 (Bazjanac 1998). IAI’s Industry Foundation Classes (IFC) are the means of achieving interoperability in this industry: A general object-oriented data model of buildings that facilitates the sharing and exchange of information among IFC-compatible software applications (IAI 1999).

The Industry Foundation Classes (IFC) data model is intended to describe building and construction industry data. It is an object-based file format with a data model developed by buildingSMART (International Alliance for Interoperability, IAI) to facilitate interoperability in the architecture, engineering and construction (AEC) industry, and is a commonly used format for Building Information Modeling (BIM). It is also an international standard that stores building data in a database, permitting information to be shared and maintained throughout the life cycle of the construction project, that is, design, analysis, specification, fabrication, construction and occupancy (Khemlani 2004). The IFC model consists of tangible components such as walls, doors, beams, furniture etc., as well as the more abstract concepts of space, geometry, materials, finishes, activities etc.

For a program to be IFC compliant, that is, to be able to import and export IFC file, it needs to be “IFC certified”. The IFC model is posted online and provides a framework for software developers to incorporate the IFC import and export capabilities within their program.

IAI publishes new releases of the IFC object model once often a while; each new model release contains new classes and schemata that enable interoperability among software applications serving additional segments of the industry. A summary of the IFC release timeline is shown in figure 5. buildingSMART currently aims for releasing major new versions of the standard with about three-year intervals, with the motivation that it strikes a balance between the need for stability to facilitate implementations, and responsiveness in incorporating new features to the standard (Liebich 2007).
The IFC object model cannot provide interoperability by itself – software developers must provide interfaces to the object model so that their software can create a “project model” that defines a subject building and then share or exchange the information contained in it. Thus, to achieve true interoperability, it is critical to have IFC-compatible software that is also useful to the industry.
3.2 IFC and Interoperability

From the point of view of the basic technical ability to exchange AEC/FM information, it can be said that the IFCs have now been established 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. From other points of view, however, the IFCs are still in a very early stage of development. Only recently have IFC-compatible software applications started to become commercially available, and, as yet, the IFCs have seen almost no actual use in industry.

IFCs are non-proprietary, and available globally to any company that defines AEC objects. The important concept here is the term object. Objects in a building, have geometry, that is, a 3D description. Objects also have properties, like their product name, finishes, and cost. Some objects are real like a door; some objects are abstract, like construction cost.

The difference between this (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, text, user works with the objects directly, using their familiar names, like wall, slab, roof, and building.

In this new paradigm, a HVAC engineer can be considered as an example. Traditionally, the architect hands him the plans, elevations and typical sections of the building. The engineer has to determine the room usage, calculate room volumes from the plans and sections, determine the construction materials and calculate the HVAC load. Only then is he able to plan the routes and sizes of ductwork and other elements, which he sends back as a new layer on the 2D plans the architect gave him.

On the other hand, in the IFC approach, the architect sends the engineer the full geometry of the building in an ifc file; the engineer immediately has access to the room volumes, can see if the architect has selected specific construction types for the walls and roof assemblies, etc. The HVAC application, accessing directly now much richer and integrated data from the architect, fills in missing design parameters and sets about designing the ductwork system. This time, his library is based on 3D objects, and his system automates the selection of these once the design system is calculated. Now he returns to the architect his service proposals; not as a set of plans,
but an assembly of 3D objects located accurately in the architect's 3D object model. The architect can now truly coordinate with the client, and later with the construction manager, as he refines the design while identifying clashes and construction conflicts.
3.3 IFC Limitations

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, applications must interpret and transform imported objects to their native objects as best as possible. As a complete 1-to-1 match is typically not possible, imported elements differ from natively created elements. Therefore, round tripping of IFC data is an unrealistic expectation; since Complex parametric IFC object types, such as doors, windows, curtain walls, stairs, railings, or complex walls, slabs, columns, etc., are not supported, because applications have different and proprietary methods to create such entities with parameters, rules, and constraints. To export these in a format that other parametric engines could support would not only be a tremendous development, coordination, and agreement effort, but also increase file size and processing time enormously (Kumar 2008).

Shortly, some of the IFC pros and cons can be named as follow:

**IFC Advantages:**

- Predictable 3D objects for exchanging data between application software(s)
- 3D object definitions facilitate interoperability discussions
- Provide a vehicle to test interoperability concepts
- Efficient with “well documented business practices” –GSA Program

**IFC Disadvantages:**

- Slowly evolving consensus standard
- File sizes are large -an IFC model is abstract and not optimized to work with specific building relationships as are vendor applications (e.g. space-wall integrations)
- Custom relationships of objects are not necessarily defined by IFCs -buildings are complex, all relationships aren’t fully facilitated (a near impossible task)
4. BIM Software Products

Two BIM software products were investigated in this research: Revit and Bentley.

4.1 Autodesk Revit Architecture

Autodesk Revit Architecture often referred to as simply Revit is a Building Information Modeling software developed by Autodesk. It allows the user to design with both parametric 3D modeling and 2D drafting elements. In addition, Revit's database for a project can contain information about a project at various stages in the building's lifecycle, from concept to construction to decommissioning. This is sometimes called 4D CAD where time is the fourth dimension. The latest released version is Revit Architecture/Structure/MEP 2012 (March, 2011) and the corresponding AutoCAD Revit Suite 2012 products.

Revit uses .RVT files for storing BIM models. Typically, a building is made using 3D objects to create walls, floors, roofs, structure, windows, doors and other objects as needed. These parametric objects — 3D building objects (such as windows or doors) or 2D drafting objects (such as surface patterns) — are called "families" and are saved in .RFA files, and imported into the RVT database as needed.

A Revit model is a single database file represented in the various ways which are useful for design work. Such representations can be plans, sections, elevations, legends, and schedules. Because changes to each representation of the database model are made to one central model, changes made in one representation of the model (for example a plan) are propagated to other representations of the model (for example elevations). Thus, Revit drawings and schedules are always fully coordinated in terms of the building objects shown in drawings.

Revit is one of many varieties of BIM software which support the open XML-based IFC standard, developed by the buildingSMART organization. This file type makes it possible for a client or general contractor to require BIM-based workflow from the different discipline consultants of a building project. Because IFC is a non-proprietary format, it is archivable and compatible with other databases, such as facility management software.
Autodesk announced at 2005 that the Industry Foundation Classes (IFC) exporter for Revit is available as open source code, licensed under LGPL. Revit has supported IFC file export since then. Models can be exported to the standard IFC file format which can be imported into any design program that is compliant with the IFC standard, enabling greater interoperability in the architecture, engineering and construction (AEC) industry.

By licensing the Revit IFC exporter code as open source software, the objective was to encourage full data exchange within a Building Information Modeling workflow, enabling Revit users greater flexibility to customize IFC file output for the needs of specific project or government IFC file input requirements. Users can add custom parameter sets to elements exported to IFCs, or custom quantities to the elements exported. Users may also, for example, change the representation of the exported elements, should they find another, more useful encoding.

Revit Architecture provides IFC import and fully certified export based on the latest IAI IFC2x3 data exchange standard. When a Revit building information model is export to IFC format, the information can be used directly by other building specialists, such as structural and building services engineers. For example, building information models developed with Revit Architecture are saved to the RVT file format. You can export the building model using the IFC format to an IFC-certified application that does not use the RVT file format (e.g. Bentley). The drawing can be opened and worked on in the non-native application. Similarly, in Revit Architecture you can import an IFC file, create a RVT file, and work on the building model in Revit Architecture.
4.2 Bentley

Bentley Systems, Incorporated is a software company that produces solutions for the design, construction and operation of infrastructure. The company’s software serves the building, plant, civil, and geospatial vertical markets in the areas of architecture, engineering, construction (AEC) and operations. Their software solutions are used to design, engineer, build and operate large constructed assets such as roadways, railways, bridges, buildings, industrial and power plants and utility networks.

MicroStation, as one of the Bentley’s main products, is an information modeling environment explicitly for the architecture, engineering, construction, and operation of all infrastructure types including utility systems, roads and rail, bridges, buildings, communications networks, water and wastewater networks, process plants, mining, and more. MicroStation can be used either as a software application or as a technology platform.
5. Case Study: 3D Model of G. G. Brown Building

As a case study to experience the probable errors of interoperability between BIM models, a 3D model of the G. G. Brown building at the University of Michigan was used (built by Lin Liu 2011). The G.G. Brown Building has three floors and a basement. The 3D model was created in Revit Architecture 2012 by importing 2D CAD drawings.

![2D CAD View of Second Floor of G. G. Brown Building](image)

Figure 6: 2D CAD View of Second Floor of G. G. Brown Building
The case study has been carried out in a few steps:

1. **Opening the 3D model in Revit Architecture 2011:**

   As mentioned above, the skin model was built using Revit Architecture 2012. When using BIM models in projects, team members use their software of preference, but even if they use the same software, they might use different versions (releases). One of the main problems of the Revit software is that there is no way to down grade a Revit project, i.e. Revit does not have 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.

   So this is one of the places that using an IFC file is the only solution. The model should be exported to IFC by Revit 2012 and imported to Revit 2011.
2. Exporting IFC file out of Revit 2012

As mentioned before, Revit has the ability to export IFC files. For doing this, after opening the model, by choosing IFC from Export menu, Revit starts building the IFC file (Figure 8).

![Figure 8: Exporting an IFC file from Revit](image)

3. Importing IFC file in Revit 2011:

After exporting the IFC file from Revit 2012, importing it to Revit 2011 was experienced. To do so, IFC option from the Open menu should be chose (Figure 9).

![Figure 9: Importing an IFC file to Revit](image)
After opening the IFC file, an error window opens mentioning the number of errors in importing the IFC file and also the title of them (Figure 10).

![Error window in Revit](image)

**Figure 10: Error window appearing after opening IFC file in Revit**

As in can be seen here, there are 188 errors in opening the IFC file. Some of them are errors in making walls, or elements being inside each other (wrong coordinates).

![Examples of errors from importing IFC file](image)

**Figure 11: Examples of errors from importing IFC file to Revit**

In order to continue opening the IFC file, the “Unjoin Elements” or “Delete Elements” option should be chosen, which apparently unjoins or deletes the elements which the errors refer to.

After opening the IFC file, it appears as follow:
Figure 12: IFC model after importing to Revit

The walls that are not in the right position can be easily seen in this 3D view.

4. **Importing IFC file in Bentley:**

   One of the goals of this case study is to compare the interoperability strengths of Revit and Bentley. After opening the IFC file in Bentley Building V8i, the software does not give any errors, but some elements are missing and some elements’ properties cannot be viewed. It should be noted that Bentley does not have the element position problem that Revit had. After opening the IFC file in Bentley it looks like as below:
Further problems regarding using IFC files in these pieces of software are discussed further in the following chapter.
6. Interoperability Issues Using Revit and Bentley

6.1 IFC File Issues Using Revit

Some of the specific issues arisen when using IFC files in Revit and some reasons behind them are as follow:

- When exporting a metric model, which has a defined survey point, to IFC, the relation between the survey point and the project base point gets converted to feet within the IFC file. When importing this IFC file, this relation is read as millimeters thus resulting in wrong origin for the imported model.

For example, a survey point that has the following relation to the project base point: X=-5000 mm, Y=-10000 mm, Z=1000 mm, Angle to true north=30°, gets defined like this in the exported IFC file:

```
#341=IFCCARTESIANPOINT((16.40419947506561,32.80839895013124,-3.280839895013123));
```

i.e. the correct coordinate for the survey point, but stated in feet. Since all lengths in the IFC file are defined in millimeters, this coordinate will be read as 16.4 mm, 32.8 mm, -3.28 mm when imported. The angle to north is exported correctly.

- Importing an .ifc file into Revit architecture 2011: an .ifc file can be imported into Revit 2012 without any problems; however when importing the same file to Revit 2011, the import is missing beams, columns, plates, etc.

- IFC takes a lowest common dominator approach to BIM. So even though Revit has IFC certified importers and exporters there is invariably a loss of data fidelity.
An example of this loss of data is the new ‘improved IFC’ plugins written for Revit Structure and MEP. This shouldn’t be required if IFC was the solution for interoperability. Autodesk could improve the IFC translators in Revit but then the problem remains: every vendor who has an application that implements IFC has to account for subtle differences in implementation or mapping to their object models. This increases the amount of testing and development required for each and every IFC application that is utilizing the IFC files (Robinson 2010).

- Archiving: It does not seem like that IFC is as any more a guarantee for archived BIM projects than a closed Autodesk file format. And regardless of which file format, would a BIM project file be a true reflection of a buildings’ as built state in 20 years’ time? The only real solution for all data is to serialize it into a readable format like XML. (Which is entirely possible with a full open API)
Figure 15: No Loss of Data in using an Open External API (Robinson 2010)

- When an IFC model is opened in Revit, the elements come in as GENERIC MODELS which are IN-PLACE. That elements coming from the IFC model such as floors, walls, columns, beams etc. should be FLOORS, WALLS, COLUMNS, BEAMS families instead of IN-PLACE.
- When an IFC file with standard settings is imported from Revit and is imported back to the same platform (e.g. Revit architecture 2012) there is some data loss such as:
  > The doors and windows are not as doors and windows.
  > The constraints related to the elements are missing.
For instance, if a wall is drawn between two levels in a model after import and export it is showing as the wall is unconnected to the top.
- When opening an IFC file of a building, the slabs and walls do not line up.
- The structural columns are gone in the IFC file.

P.S. AutoDesk has confirmed that the Revit 2012 IFC Export is broken and will be updated in a future release.
6.2 IFC File Issues Using Bentley

IFC are the ‘lowest common denominator’ of all involved applications, therefore, high-end functionality in some applications is being reduced to the level of functionality that all applications can support. So-called ‘round tripping’ of IFC data, i.e. importing an IFC-file into the application which exported it or any other IFC-compliant application without any loss of data or functionality, is neither a current objective of the IFC Extended Coordination View nor a certification criteria, requirement, or use case for a number of reasons:

- 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. NB: 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 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-file re-imported (round tripped) cannot create the original application data, thus certain features can no longer work.
- Parametric shapes can be exchanged for a subset of building objects, such as standard walls, beams, columns, slabs, openings, doors and windows. However, parametric shapes of complex IFC entities, such as curtain walls, stairs, railings, or more complex walls, slabs, doors, windows, etc., are not supported, because applications have different and proprietary methods to create such entities with parameters, rules, and constraints. To export these in a format that other parametric engines could support would not only be a tremendous development, coordination, and agreement effort, but also increase file size and processing time enormously.

The only requirement for round tripping of IFC data is the preservation of GUIDs\(^1\) (Globally Unique Identifier), even if IFC entities are downgraded to proxies and the geometry is converted

---

\(^1\) GUID is a unique 128-bit number that is produced by the Windows OS or by some Windows applications to identify a particular component, application, file, database entry, and/or user.
to more basic geometric representations. Therefore, when a Bentley model is exported to IFC, then imported back into Bentley, it is no longer identical to the original model; hence certain application functions no longer work as before (Pniewski 2011).
6.3 Quick Comparison between Revit and Bentley

A quick comparison between missing elements and errors in Bentley and Revit revealed the following results:

<table>
<thead>
<tr>
<th></th>
<th>Bentley</th>
<th>Revit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Element geometry</td>
<td>No issues found</td>
<td>Some corrupted</td>
</tr>
<tr>
<td>Element relative position</td>
<td>No issues found</td>
<td>Affected by element geometry</td>
</tr>
<tr>
<td>Element color coding</td>
<td>No issues found</td>
<td>No issues found</td>
</tr>
<tr>
<td>Entity and element count</td>
<td>Incomplete</td>
<td>No issues found</td>
</tr>
<tr>
<td>Schedule of values</td>
<td>No issues found</td>
<td>Errors</td>
</tr>
<tr>
<td>Entity attributes</td>
<td>Not visible</td>
<td>No issues found</td>
</tr>
<tr>
<td>Entity property sets</td>
<td>Not visible</td>
<td>Some missing</td>
</tr>
</tbody>
</table>

Table 2: Comparison between Bentley and Revit
7. Conclusion

7.1 Future of BIM and Interoperability

Despite current issues with interoperability, there is much to recommend a BIM-based work process. For the many structural engineering firms currently using BIM, maintaining leading edge technical capabilities, realizing process improvements, improving document coordination, and enhancing project opportunities are ample justification for using BIM. Interoperability, even in its current limited form, results in some degree of process improvement.

But interoperability issues will continue to limit users’ ability to freely exchange data between software packages. Current means of achieving interoperability consist of mixed proprietary alliances and industry standards still in development. True interoperability is dependent on the further development of a robust industry standard, and software vendors’ incorporation of this standard into their products.

The knowledge that already exists relates to general BIM issues, project stakeholders, project approaches, software applications, interoperability, standards, and data models. IFC has been found the only well developed, non-proprietary, open and public data model for AEC existing today (and therefore utilized throughout the research work in this research report). It has emerged that IFC is a standard of a high quality, being expressive, expansible, and providing a facility of a standard way of addressing non-standard extensions. IFC is also sufficiently mature to be utilized in BIM. IFC’s link to XML gives added opportunities; therefore, ifcXML should not be underestimated as another global standard and utilized in projects, hand-in-hand with IFC, along with other industry-standard models or electronic data exchange formats (like CIS/2).
7.2 Future Work

The research problem invites a range of topics that could be extended to other areas, still relevant to BIM’s interoperability, but falling outside of this research report due to its size limitation and the time restriction. The knowledge gained during the research, brings a number of related areas that could be considered for the future.

- Other options of sharing BIM information could be investigated, i.e. using emerging technologies such as the iPad applications. Very recently, Autodesk announced their return to AutoCAD for the Mac, bringing 3D free-form design with a graphical user interface, and the option of viewing, editing and sharing files on the iPad, iPhone, and iPod Touch (Autodesk Inc. 2010).

- The question should be answered that what is the source of interoperability issues: the software or the standards? And Are the software vendors in a position to catch-up with the advances of standards development?

- Once interoperability of 3D files is mastered, BIM could be evaluated for 4D, 5D, and beyond, bringing additional dimensions to the model, such as ‘safety’ and ‘sustainability’ to start with.

- New solutions, ready to interoperate, could be developed and ‘sold’ to the market by the software vendors being now equipped with the ‘ammunition’ of interoperability quantification and the specific user requirements.

- Finally, the knowledge gained in live BIM projects and during prototyping and testing could be shared with other professionals in editorials, presentations, and trade conferences.
7.3 Possible Scenarios

The following three theories represent the possible cases that might be true regarding BIM interoperability:

Theory 1: Success of resolving interoperability issues depends on methods employed to discover such issues. This theory can be validated, as the success of resolving interoperability issues does depend on methods employed to discover such issues. These methods, like prototyping and testing, have been identified and implemented in the research.

Theory 2: There are known issues with interoperability and such issues could be specifically identified and named. This theory can also be validated, but with comments. There are certainly known issues with interoperability and many of them have been identified in relative researches. Due to the nature of the methods employed and testing limitations, it is not known to the end whether all of the issues have been identified. In general terms, many issues depend on specifics of the project, such as workflows, software applications used, and standards utilized.

Theory 3: IFC are sufficiently mature to be adopted in projects utilizing BIM; teams are prepared to undertake a challenge of interdisciplinary collaboration while submerging in BIM. This theory could be validated, but with caution. IFC are sufficiently mature to be adopted in projects utilizing BIM, bearing in mind the initiatives needed to be in place in order to improve the standards. Many teams are prepared to undertake the challenge of utilizing the standards, which comes with the increasing popularity of BIM. They will succeed and gain benefits of this approach and the emerging technologies, providing they are sufficiently educated about the standards and are able to recognize the benefits as well as the limitations. Such knowledge about interoperability sometimes amounts to identifying what information can be transmitted in a non-proprietary format like IFC or exchanged by alternative means and still provide sufficient basis for interoperability between practices (Pniewski 2011).
7.4 Conclusions

Interoperability affects entire AEC industry, involving the build teams who utilize wide variety of specialist software applications and share the data among the interdisciplinary teams. Interoperability issues only interfere and hold back that exchange, leading to inefficiencies, abortive work, and errors. 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 attracted by using duplicate software and the time lost due to document version checking and ineffective processing the 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. In addition, interoperability of BIM software application greatly impact on projects’ quality assurance, and most importantly affects customer satisfaction (Pniewski 2011).

The key factor inviting interoperability issues is the continually advancing and complex nature of AEC projects today, the volume of specialism disciplines involved, and the software solutions employed. These days are still early days for implementation of BIM and the technologies it brings. 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 of improving it. Related research exhibits 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 advice on how to remove the obstacles in attempt to increasing the chance of achieving interoperable BIM in collaborative AEC projects.

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 the effort is required to accurately define IFC Views for the project-specific workflows (Eastman et al. 2008). This should follow with examination of the process flow diagrams and verification of these with the software functionality through testing.

Separating elements of the model has been found a very effective way of resolving 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.

Continuous effort should be maintained by software vendors to certify their latest versions of applications, and by buildingSMART to obtain ISO certification for the remaining parts of the IFC Object Model and to improve IFC certification process.

Although IFC is the dominant format for BIM models today, other standards or specifications should be considered to use in combination. Although interfaces between the employed standards solution may cause challenges, the use of multiple standards would only increase a chance of interoperable model or its components.

Continuous education about standards would help managing expectations. It needs to be realized that it is unrealistic to expect complete level of interoperability among the authoring software applications. Good step towards improving interoperability would be to differentiate the model information best suited for transmitting in a non-proprietary format (such as IFC or ifcXML), from the information intended for the exchange while employing proprietary software programs such as original authoring applications. This should follow with examination of vulnerable areas of the files on how they behave upon adoption of each of the above approaches.

Software vendors and the users should be encouraged to take a part of the standardization process by performing interoperability testing, actively participating in standards organizations like buildingSMART, and sharing the results with others.
8. References:


Kumar, S., (2008). “Interoperability between Building Information Models (BIM) and Energy Analysis Programs”, MS Thesis, University of Southern California, CA, USA.


Eastman, C., “BIM and Interoperability for Precast Concrete”, Charles Pankow Foundation Research Project, Georgia, USA.
