

BUILDING INFORMATION MODELLING (BIM) SOFTWARE INTEROPERABILITY: A REVIEW OF THE CONSTRUCTION SECTOR

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Building Information Modelling (BIM) is continuing to evolve and develop as the construction industry progresses towards level 2 maturity. However, one of the core barriers in this progression is the aspect of interoperability between software packages. This research and paper stems from a Knowledge Transfer Partnership (KTP) where both industry and academia come together to address this shortcoming within the sector. One of the core objectives of this partnership and the aim of this study is investigating potential solutions to this barrier, while also developing best working practices to be applied in industry. Using one of the case studies from this partnership (a temporary steel structure), this paper demonstrates a potential solution to addressing interoperability within structural analysis and detailing packages, MasterSeries and Revit respectively. The findings of the research indicate that a process based approach rather than that of additional software coding as being the preferred solution. The results of this preliminary research will aid in the development of the topic of interoperability within the sector, while also developing the knowledge and competencies of the parties within the KTP. The findings are explored further, by providing an overview of the resolution process adopted in this case study, in overcoming the interoperability that arose as the project progressed. It is envisaged that this study will assist the construction sector and its adoption of BIM technologies, while also addressing the critical aspect of operability between software.

Keywords: building information modelling, BIM, interoperability, knowledge transfer partnership, structural analysis.

INTRODUCTION

Building Information Modelling (BIM) has varying connotations, not only within the construction sector, but throughout the built environment. As a result, there are numerous and often conflicting definitions of BIM; particularly within the construction sector. Notwithstanding this, one of the most recognised definitions provided is from the BIM Task Group (2013), which states that BIM is “*value creating collaboration through the entire life-cycle of an asset, underpinned by the creation, collation and exchange of shared 3-dimensional models and intelligent, structured data attached to them*”. Filippo Brunelleschi, the most notable master builder from the period immediately prior to the Renaissance, used BIM to vault the massive dome over Santa Maria del Fiore in Florence in 1419, as illustrated in Figure

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1 (Garber, 2014). From this premise, it is noticeable that BIM is not just a 3D model, nor an innovative technology, but an overarching philosophy in the management and coordination of information among stakeholders. Therefore, this demonstrates that BIM integrates various forms of required data into one cohesive and integrated model, where all internal stakeholders to a project, including both design and construction, have the ability to digitally manage and integrate the often complex procedure of building prior to actual construction (Kensek and Noble 2014). A differentiating factor between traditional 2D drafting and 3D BIM modelling is that BIM objects contain intelligence within, often referred to as metadata, while in 2D Computer Aided Design (CAD) software, all elements are signified by a series of lines and points.

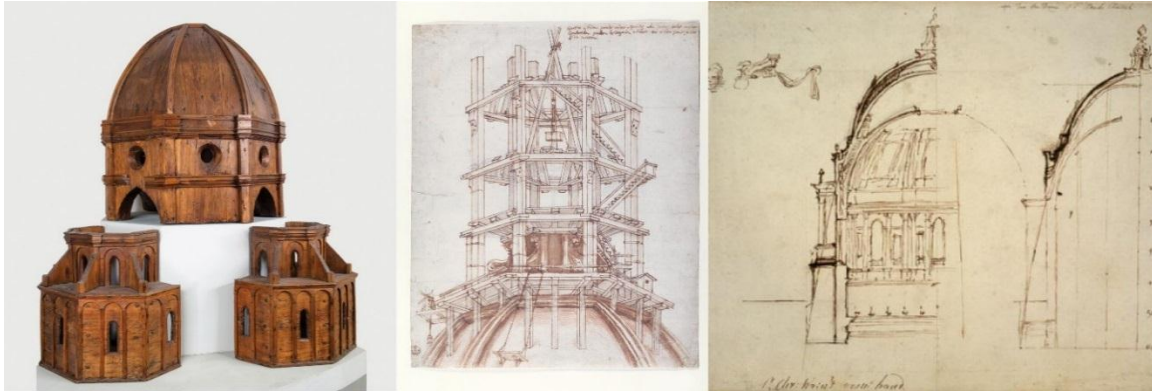


Figure 1: Filippo Brunelleschi 3D model and drawings for the Santa Maria del Fiore's dome

However, with this premise there emerges one of the core inhibiting factor in the widespread endorsement and application of BIM within the built environment - software interoperability. With the emphasis on the collaborative nature founded on data transfer, the ability of various software programmes and underlying data to interrelate and communicate effectively comes into question. The Business Dictionary (2015) defines interoperability as the ability of a computer system to run application programmes from different vendors, and to interact with other computers across local or wide area networks regardless of their physical architecture and operation systems.

Subsequently, software interoperability has emerged as one of the most inhibiting factors to the widespread adoption of BIM within the construction sector (Goedert and Meadati 2008). Various types of BIM interoperability exist including the lack of data transferring (missing data), erroneously translate data (objects imported differently in various software as illustrated in Figure 2), and files with a unique format that simply will not open in a different software platform.

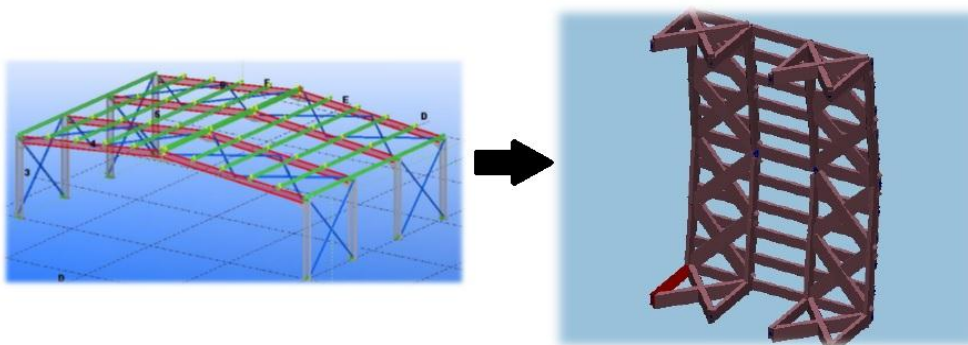


Figure 2: Wrong translation of data changed the default orientation of the structure

According to a GCR 04-867 report, published by the National Institute of Standards and Technology (NIST), the lack of operability between software platforms cost the United States of America approximately \$15.8 billion in 2002 alone, prior to the widespread emergence of BIM within the construction sector; a figure which equates to £10 billion in the United Kingdom. Therefore, it is essential that the construction sector, not only acknowledges, but takes proactive steps to mitigate and preferably eliminate interoperability between the respective software packages in the pursuit of attaining level 2 BIM as directed by the United Kingdom Government mandate. As one of the leading inhibiting factors curtailing the mass adoption and widespread implementation of the BIM process within the sector, this supports the aim of this paper and underlying research to address and provide solutions to industry. This research and subsequent findings will assist both industry and academia to mitigate this adverse characteristic, while also assisting software vendors and users alike, in resolving interoperability within the BIM process. Subsequently, through this and other accompanying research on the subject, it is anticipated that interoperability may be mitigated through hardware or software mechanisms that follow open standards such as Industry Foundation Classes (IFCs).

BIM AND SOFTWARE INTEROPERABILITY

Building Information Modelling, or BIM as it is more commonly referred to, is the integration and unification of communication among internal stakeholders to a project, with an intelligent 3D model as the platform on which to convey this intent. However, in the pursuit of facilitating this ideology, there is a necessity to accommodate the numerous of software platforms and the associated exchange of data. This has resulted in the emergence of an inherently complex and diverse aspect to the BIM process - software interoperability (Kensek and Noble 2014). Grilo and Jardim-Goncalves (2010) highlight that the goal of seamless global interoperability is far from being realised, with Froese (2010) reiterating that with this change in management perspective, more operable information and communication technology must be adopted. Moum (2010) further illustrates and acknowledges that this trait is compounded due to its proliferation within stakeholder engagement, not only internally within an organisation, but more critically, also in external stakeholder engagement.

Regardless of the mechanisms used to convey such information, be it cloud or in-house server based systems, the subject of interoperability can inhibit such interactions. Redmond *et al* (2012) reiterate this premise, particularly in relation to inhibiting data exchanges using cloud based systems. Singh *et al.* (2011) provide insight into the aspect of BIM communication and facilitation using a server based system which concludes that a greater emphasis needs to be placed on the development and consideration of the technical aspects when considering hosting of a BIM model; thus minimising interoperability among stakeholders. Regardless Gu and London (2010) advocate that in order to facilitate BIM adoption within the Architectural, Engineering and Construction sectors, it is necessary to address the technical limitations inhibiting its widespread implementation.

Čuš Babič *et al.* (2010) acknowledge this including the aspect of interoperability within the sector, by highlighting that it is not a new phenomenon. To address this shortcoming, the introduction of industry foundation class or IFC files emerge, to assist in mitigating interoperability. However, Čuš Babič *et al.* (2010) concludes that interoperability is a significant factor which adversely affects numerous projects.

Tanyer and Aouad (2005) advocate the introduction and utilisation of IFC files to assist in the mitigation of interoperability while Isikdag and Underwood (2010) outline that it is still the preferred method to date. Grilo and Jardim-Goncalves (2010) outline that the IFC file format allows the sharing of intelligent information contained within a BIM model; however, Steel *et al.* (2012) argue that further development and refinement is necessary to fully overcome the limitation of interoperability using this format. Redmond *et al.* (2012) aptly summarises the initial problem with IFCs in that they are not intended to store and carry all relevant data for all multi-featured construction processes; hence their limitations going forward.

RESEARCH METHODOLOGY

With the aim of this paper to develop potential interoperability solutions for industry and academia, there is a necessity to develop and articulate a clear methodology in doing so. This research is based on a detailed study of BIM interoperability between Autodesk Revit and Finite Elements Analysis software, Nemetschek Scia Engineer and MasterSeries, using two construction projects as case studies. A case study approach is adopted in this instance as Yin (2013) argues that it is the most beneficial approach in explaining present circumstances while also facilitating explaining a causal link. More than one case study is utilised as Yin (2013) advocates using multiple sources of information to facilitate triangulation to verify the results obtained. Yin (2012) advocates the use of an explanatory or evaluate case study research to explain and appraise the various interoperability aspects under scrutiny.

In order to facilitate the assessment of each of these software platforms, it is necessary to identify suitable case studies for inclusion in the research. A two stage selection process is adopted, where firstly six potential case studies are identified for inclusion in the research. To facilitate this selection process, criterion sampling is adopted where each of the selected case studies have to meet a set of requirements. The criteria included size (sufficiently large enough structure), complexity (sufficiently complex), and positive client consent for participation in the research. The various case studies are located throughout the United Kingdom. Once six potential case studies are identified, random sampling is then introduced to remove researcher bias in the identification of the preferred case studies.

Subsequently, two case studies are randomly selected. The first case study is a concrete structure (water treatment plant), where Scia Engineer is used and the second case study is a steel structure (retail unit), where MasterSeries is used for analysing the steel frame. In each of the respective case studies, two file exporting techniques are explored, due to their prevalence in the industry; exporting the model using Industry Foundation Classes (IFC), and exporting through a direct link between Autodesk Revit and the respective software under scrutiny (Scia Engineer or MasterSeries).

Industry Foundation Classes (IFC)

In 1994, Autodesk developed an industry consortium, known as the Industry Alliance for Interoperability, which later, in 1997, was renamed to the International Alliance for Interoperability (IAI). This consortium has developed an open and neutral BIM format called Industry Foundation Classes or IFC. According to Applied Technology Council (ATC) report (2013) *“The Industry Foundation Class (IFC) file type represents a means for sharing construction and facility management data across various software packages used in the architecture, engineering and construction*

industry and facility management industry.” In 2005, IAI was renamed again to BuildingSMART and since then it continuously develops and maintains IFCs. IFCs, which are critical and definite components of BIM file sharing, are used by various BIM software vendors to setup and facilitate a computer-readable model. This contains all the data and information of the parts within the model and their relationships, to be transferred among stakeholders within a project. There are six different versions of IFC available (1.5.1, 2.0, 2×, 2×2, 2×3 and 2×4), with the IFC 2×3 format used in this instance.

Bi-directional link between Revit and Finite Elements Analysis (FEA) software

Direct links are extensions (add-ons) and data exchanges developed to facilitate specific actions between two software platforms. In this instance, direct links are introduced between Revit and FEA software to facilitate the data exchange process. These extensions are direct links between one software and another, and unlike IFC files, they are not cross compatible and do not work with any other software or systems outside of those intended. Since these links are developed specifically for the specific software platforms intended, they do not take into account any external considerations or scenarios. As a result, the data exchanged is normally of high quality and the final result is more accurate in comparison with other interoperability methods. However, it is limited by the environment in which the data can be transferred. In this instance, a direct link between Autodesk Revit and Scia Engineer version 3.0.254, developed by CADS, and a direct link between Autodesk Revit and MasterSeries 2014 are used, to assess interoperability in the respective software platforms.

CASE STUDY ANALYSIS - CASE STUDY 1

The first case study for consideration is that of a water treatment plant consisting of a concrete and steel structure. This new water treatment plant is a leading facility, designed to meet the advanced needs in water filtration and treatment and is located in the United Kingdom. The reinforced concrete water retaining tanks and the steel framed superstructure, including crane beams, are modelled in Autodesk Revit Structure (Figure 3); however, for the purposes of this paper, only the concrete structure is exported.

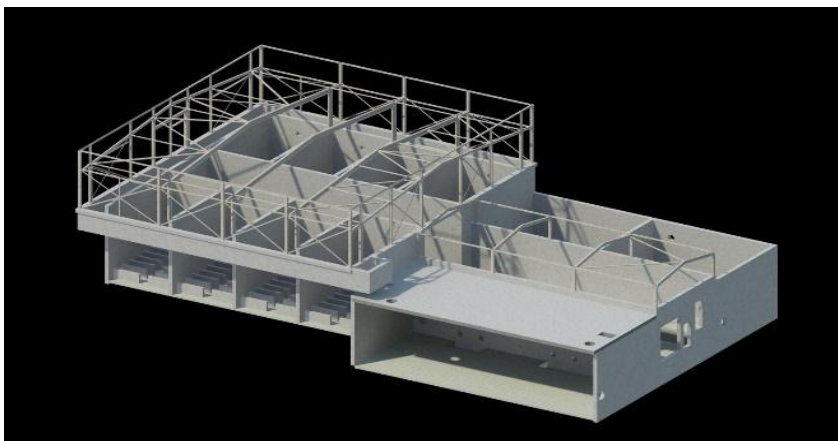


Figure 3: - Autodesk Revit model of case study 1: water treatment plant

Exporting to Scia Engineer

As outlined in the methodology, two formats are considered for migration of data from Autodesk Revit to Scia Engineer; firstly using IFC files and secondly, using a

direct link. In the first instance, when using IFC format, exporting and importing the IFC model is relatively straightforward, where the user is presented with a limited number of options to facilitate the process. In the second instance, in using the direct link approach, in order to use the add-on to export the model directly to Scia, the user must run Autodesk Revit using administrator rights. Unlike using the IFC method, the user has more options to consider during this process and can select desirable elements to be exported. Figure 4 shows the exported models in Scia Engineer.

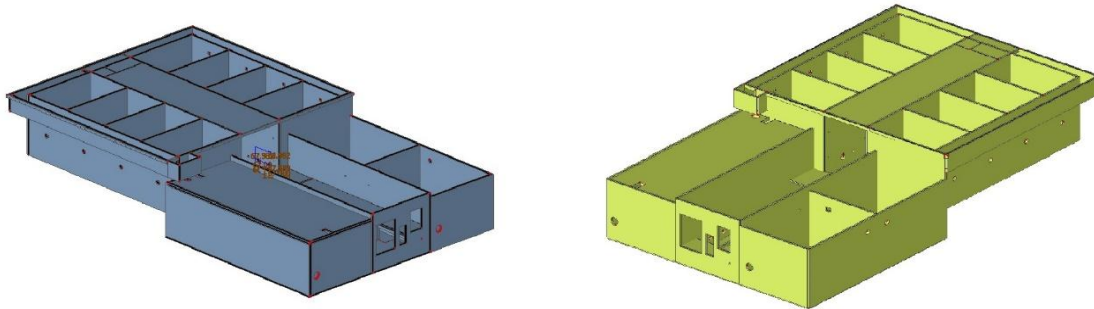


Figure 4: Exported models - IFC (left) and direct link (right)

Although the physical models look similar and appear to be accurate, further investigation reveals that the IFC model is imported with the incorrect materials assigned, while the direct link model has the correct materials allocated. In this case, where Scia Engineer fails to recognise a material using the direct link facility, it will provide the user with the opportunity to select the correct component manually. However, in the case of the IFC format, the user is not provided with such an opportunity within the IFC model and as a result, is one of the major shortcomings in this process based solution.

The Autodesk Revit and Scia Engineer direct link add-on not only highlights exported and non-exported elements within the Autodesk Revit model, but also provides a full report on the exporting process. As Figure 5 illustrates, the report represents a number of exported and non-exported elements and notifies the user of potential errors in the exported model, along with a suggested solution. Further refinement is suggested in this process where a model overlay is provided to assist in relating the notations with the respective areas of concern.

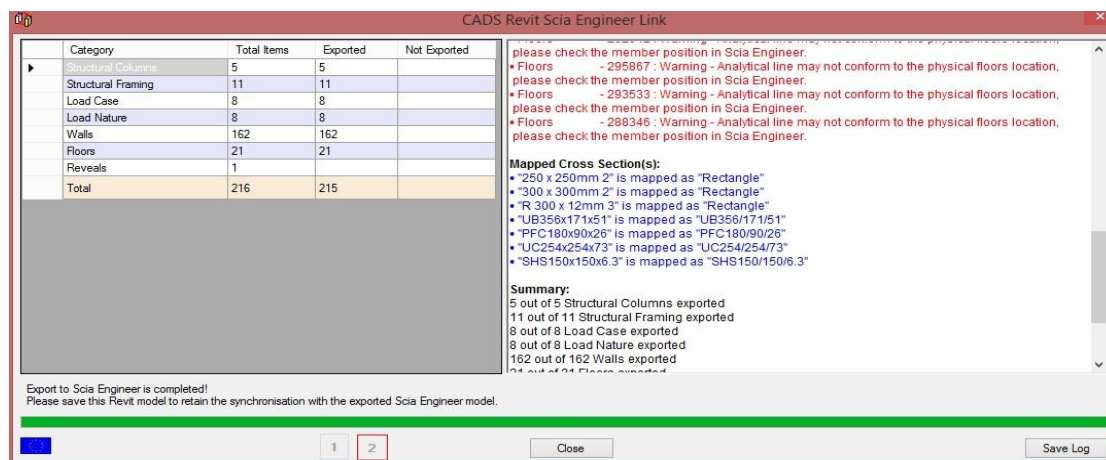


Figure 5: Sample report created by Autodesk Revit and Scia Engineer direct link add-on

One of the significant advantages of using a direct link format for file transfer, is the potential to facilitate a bi-directional transfer of data. This option will automatically

update the initial model in Autodesk Revit, based on any changes which have been made to the model in Scia Engineer. However, if any changes are being applied in the context of the IFC model in Scia Engineer, the user must re-save the file in IFC format and re-open it in Autodesk Revit. There is no option available to apply changes and update the initial Autodesk Revit model directly. However, there is a note of caution where bi-directional links are introduced. Such aspects as legal and liability assignment is called into question, where one stakeholder makes changes to a model which adversely affects another without consent. Additionally, the aspect of intellectual property is also called into question where interoperability is concerned. Such factors, although beyond the scope of this paper, must be acknowledged and counteractive measures assigned to mitigate or preferably eliminate such concerns between the various internal stakeholders to the project.

CASE STUDY ANALYSIS - CASE STUDY 2

In this instance, this case study is a three/four storey retail unit, bounded on three sides by a live shopping mall, retail units and car park access. The structural model designed using Autodesk Revit includes the steel frame, with composite metal deck flooring on a pile foundation and a reinforced concrete partial basement. This project is located in Northern Ireland and illustrated in Figure 6.

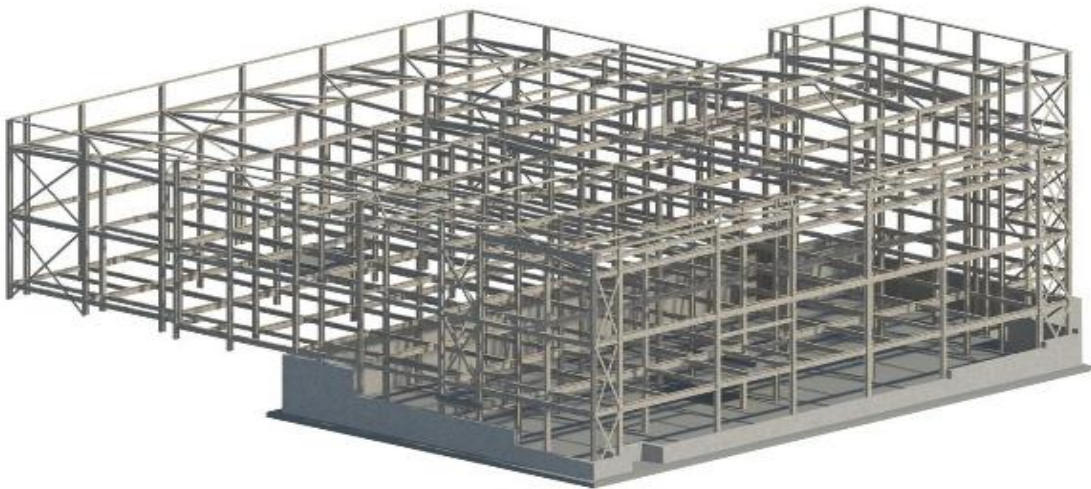


Figure 6: Autodesk Revit model of case study 2: retail unit

Exporting to MasterSeries

In relation to the second case study where MasterSeries is introduced to facilitate the structural steel construction, both IFC format and a direct link approach is adopted to assess interoperability. In the case of IFC, after saving the model in IFC format, the model is imported, extracted and loaded in MasterSeries. As mentioned before, exporting and importing IFC files is an uncomplicated process; however in this instance, MasterSeries offers a number of options before extracting the model, such as Y co-ordinate offset and importing or ignoring walls.

In the context of using the direct link approach, the user needs to open the Link Management Centre, where the add-on section is located. The Link Management Centre offers various options, for example, users can export the whole model or selected elements within the model. Moreover, the user can create a bi-directional link, which provides the ability to export the model back from MasterSeries to Autodesk Revit, or a unidirectional link, which is a one-way export to MasterSeries. Additionally, it is possible to map the steel sections and Revit Family manually in the

Link Management Centre. Both the exported models using the direct link and IFC format are shown in Figure 8.

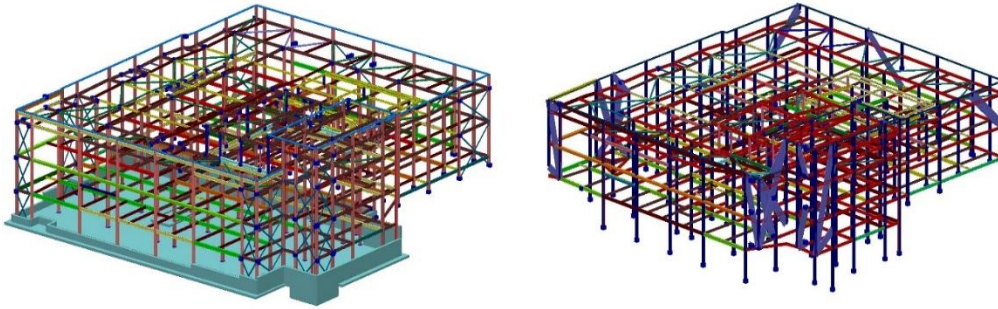


Figure 7: Exported models - direct link (left) IFC (right)

As Figure 7 demonstrates, concrete walls and slabs are omitted in the IFC model in MasterSeries. Moreover, the IFC model failed to recognise and translate one of the steel families in Autodesk Revit; thus numerous errors and omissions emerged. As a result and to compensate for this omission, MasterSeries replaces the omitted section with an incorrect and oversized section. In contrast, if Autodesk Revit and MasterSeries link failed to recognise an Autodesk Revit family, it prompts the user to define the component manually.

The Autodesk Revit and MasterSeries direct link has also a bi-directional functionality, which permits the export and import of the model between Autodesk Revit and MasterSeries. This feature facilitates updating the model in one software, based on changes which have been made to the model in another. Conversely, changes made to the IFC model need to be applied manually to the initial Autodesk Revit model. The Autodesk Revit and MasterSeries link can produce an export log (Figure 8), that contains information relating to the exporting process and shows the export summary; thus providing a detailed overview of the components exported.

```
4/14/2015 03:54:02 PM: Frames(Id=900233):P1 = P2
4/14/2015 03:54:02 PM: Beam/Brace not exported for element 900233 - The element has 1 nodes. Only 2 noded element are supported.
4/14/2015 03:54:02 PM: Frames(Id=901325):P1 = P2
4/14/2015 03:54:02 PM: Beam/Brace not exported for element 901325 - The element has 1 nodes. Only 2 noded element are supported.
4/14/2015 03:54:02 PM: Frames(Id=902603):P1 = P2
4/14/2015 03:54:02 PM: Beam/Brace not exported for element 902603 - The element has 1 nodes. Only 2 noded element are supported.
4/14/2015 03:54:02 PM: Frames(Id=904330):P1 = P2
4/14/2015 03:54:02 PM: Beam/Brace not exported for element 904330 - The element has 1 nodes. Only 2 noded element are supported.
4/14/2015 03:54:02 PM: Frames(Id=905116):P1 = P2
4/14/2015 03:54:02 PM: Beam/Brace not exported for element 905116 - The element has 1 nodes. Only 2 noded element are supported.

Export Summary:
Frames: 847 exported, 19 skipped
Columns: 114 exported, 0 skipped
Walls: 19 exported, 0 skipped
Materials: 3 exported, 0 skipped
Sections: 31 exported, 0 skipped
Thicknesses: 4 exported, 0 skipped
Floors: 5 exported, 0 skipped
Grid Lines: 19 exported, 0 skipped
Levels: 15 exported, 0 skipped
Boundary Conditions: 0 exported, 0 skipped
Rigid Links: 0 exported, 0 skipped
Frame Releases: 848 exported, 0 skipped
```

Figure 8: Autodesk Revit and MasterSeries direct link export log

One aspect of concern in direct link is the different format adopted in the numbering of the nodes. According to the MasterSeries, the algorithm used for numbering nodes in Autodesk Revit is slightly different to the one adopted in MasterSeries. However, it is possible to renumber all nodes, based on the MasterSeries numbering format, within MasterSeries, where an option is provided in the main menu of the software to do so.

CONCLUSIONS

Building Information Modelling (BIM) has quickly become the leading platform for the facilitation and dissemination of communication in the architecture, engineering

and construction industry; a factor evidence in the proliferation and emergence within the built environment. With this and the evolution of the BIM process and underlying software packages, interoperability emerges and has come to the fore as one of the leading inhibiting factors in the proliferation of the BIM process within the construction sector. The necessity of operability between BIM software, particularly between CAD and FEA software, is undisputed and is one of the clear failings which needs to be addressed.

This paper reviews two approaches to mitigate interoperability between these two software platforms; using IFC's and direct links within software packages. Direct links are developed to exchange data between two BIM software platforms, while IFC files can be opened and modified by various BIM software packages. This feature has brought both negative and positive viewpoints for IFC files as also iterated in the literature reviewed. First of all exporting IFC files is not complicated, and it does not need an extra add-on or extension to be installed; however, there is clear limitations on the date that can be transferred, thus limiting its success. Secondly, IFC files can be opened by almost all BIM software, including CAD and FEA software; however, this option has decreased the accuracy and precision of the exported model.

In contrast, direct links are extra add-ons which must be installed separately on each of the respective systems handling the models in question and they only work with two BIM software platforms on which they are designed. This is one of the core limitations of this process; however this has aided software developers to refocus more on the details and accuracy used within this file handling and transfer process. As a result, the exported model through direct links is usually more accurate than that of IFC model. Therefore, this paper highlights that, although Industry Foundation Classes (IFCs) are the means to exchange data and information related to a BIM project, using direct-link to transfer data is more reliable and accurate process.

However, there are additional points of concern emanating from this and other research on data exchange utilising the BIM process. Such aspects as the legal ramifications of integrating bi-directional links between working models, particularly between organisations and the subsequent liability that will inevitably ensue must also be considered and investigated further. Additionally, aspects such as intellectual property rights and ownership issues also emerge and must be considered by the industry before advocating the widespread success of mitigating interoperability outside of software and their supporting systems. Hence, it is suggested that further research be undertaken in these areas, to substantiate the findings herein.

This paper and others included in the literature reviewed, all argue that BIM interoperability is of concern, yet this aspect has yet to be resolved. This research demonstrates that this is still an issue, particularly in relation to BIM interoperability between computer aided design and structural analysis software; however, potential solutions are tabled and reviewed with varying success. Through a process based approach, industry and academia alike can mitigate and in some instances eliminate software interoperability through adopting a process based approach rather than relying on software coding, as is often the case. Subsequently, this can assist companies in the selection of the most efficient and appropriate method to facilitate the data exchange required between BIM software packages. It is envisaged that this paper; although only tabling initial findings from a knowledge transfer partnership, can assist in facilitating those who wish to adopt and implement a fluid data transfer

process encompassing the BIM process within their respective organisations and sectors as a whole.

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