Leveraging the Potential of BIM towards Sustainable Construction

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Abstract. The need to recognize the importance of sustainable construction is becoming a major concern. The innovative technologies around the construction industry can be of major help to achieve the aim of sustainable construction. There are various diverse sustainability rating frameworks around the world, everyone with the same aim of improving the performance of whole building to achieve the goals of creating a healthy built environment. Integration of data is key to sustainable construction which needs a shift from traditional methods of sharing information among various stakeholders. Nowadays, BIM is emerging as more dominant technology by progressively integrating more and more people of the AEC industry. However, the uninterrupted use of digital data information along the complete process sequence falls notably behind other industry sectors. For a successful construction project, an uninterrupted understanding and widespread exchange of information among these stakeholders is essential. Main role of BIM is to improve the collaboration and communication between various people and phases of construction by integration of exchange of information. BIM process, implemented successfully is able to improve the delivery of information in a project and reduce extra cost incurred due to design changes during subsequent construction phases. In this paper to achieve a sustainable BIM model, the capability to share the information using most popular open source, vendor neutral platform IFC, between two of the most accepted BIM software was investigated. Round trip tests were performed for the IFC models produced in two software and an evaluation is made in terms of geometric distortion, information loss and misrepresentation. Several issues were found in exchanging both object geometry information and other semantically significant data. Complete exchange of geometry was not observed in any of the exchanges. The reason for these imperfections is due to the fact that different software prefer to use methods to generate the information in their internal data schemas.

1. Introduction
Like the two faces of a coin, every technology and process has pros and cons. The construction industry is not an exception here. It is an active industry in both developed and developing countries. On the one side the crucial role of construction industry in social, economic growth and development of any country cannot be neglected. It is considered as one of the key pillars for the economic growth of any nation. However, for the past few decades, construction industry is facing the criticism of
impacting the environment in a negative way. Environment impacts of this industry are attracting the concern of researchers and policy makers. All the building operations such as construction, operation, maintenance, renovation and demolition are considered as responsible for the major cause of air pollution, noise pollution, water depletion, 36% of world’s energy consumption, 40% of CO₂ production and burning up of major part of natural resources. It is noted reality that concrete is the most broadly utilized structural material, which delivered in excess of 10 billion tons for every year on the planet [1]. With this enormous amount, the construction business is a significant consumer of huge amounts of natural resources and great deal of energy and responsible of air contamination. Carbon dioxide discharges are the primary ozone harming substance outflows affecting the sustainable development. Large amount of carbon dioxide discharged during the creation of concrete is one of the primary sources behind the Earth-wide temperature boost.

The need to recognize the importance of sustainable construction is becoming a major concern. The innovative technologies around the construction industry can be of major help to achieve the aim of sustainable construction. There are various diverse sustainability rating frameworks around the world, everyone with the same aim of improving the performance of whole building to achieve the goals of creating a healthy built environment. Sustainability in construction is not only all about the installation of energy-efficient mechanical systems. It’s a way of thinking that impacts each part of the plan and development stages just as the continuous support and activity of the structure going ahead. Integration of data is key to sustainable construction which needs a shift from traditional methods of sharing information among various stakeholders. Information Technology has changed a wide scope of industrial sectors and the Architectural, Engineering and Construction Industry (AEC) industry is also advancing rather fast with the advent of technology. Construction companies are now adopting digital tools to plan, design, construct and operate the buildings and to make enhanced decisions, boost productivity, get better construction site safety, and lessen risks [2]. However, the uninterrupted use of digital data information along the complete process sequence falls notably behind other industry sectors. The planning and understanding of a building project is a complex procedure involving a variety of stakeholders from diverse fields of proficiency. For a successful construction project, an uninterrupted understanding and widespread exchange of information among these stakeholders is essential. Seamless exchange of information between domain-specific tools is essential for capturing all the information of a building from its commencement to operation.

Nowadays, Building information modelling (BIM) is emerging as more dominant technology by steadily integrating more and more people of the AEC industry. BIM the acronym for Building information modelling is a process of using 3D virtual representation of buildings, for collecting and managing building data from the start of the project to the operation of building through its construction. By applying the BIM technique, everything begins with a 3D digital model of the building. A much more thoughtful utilization of computer proficiency in the design, construction and operation of building projects is recognized [3]. As compared to the conventional methods of producing and sharing information in drawings, BIM creates a full digital physical appearance and functional description of built facility, preserves and share all information using comprehensive digital illustrations known as building information models. BIM model also known as building information container, not only incorporates the three-dimensional geometry of building units at a defined level of detail. In addition, it also includes non-physical concepts such as materials, properties, spaces, schedules, zones and parametric rules as well as the relationships between the components.
Figure 1 A rich set of semantic information provided by BIM model

Parametric information attached to the objects can be used to automatically generate building documents such as sections, plans, elevations etc [4]. Figure1 represents rich set of semantic information provided by BIM model. The main characteristic of BIM model is its ability to convey semantics, which means all its elements possess a typical meaning that can be used for energy performance, analysis and design of structural elements, fire simulation, predict performance, to estimate costs and execute construction. Parametric representation combined with objects provides the detailed properties and their relationships with other objects in the model.

2. BIM Workflow
In an ideal BIM workflow, working with BIM methodology, means not only using the simple combination of geometric shapes, materials, appearance with high quality information of components of building. However, the main contribution of BIM comes from its revolutionary contribution to bring all the team members into a collaborative workflow in order to integrate all information in a single integrated model derived from every phase of construction process: from architects, structural engineers, energy performance tools, fire safety simulation and to asset management. It act as common platform for all the stakeholders, breaking down silos and encouraging full cooperation, bringing all professionals under one roof into a collaborative workflow. Where everyone concerned in a project can explore the model to add or retrieve graphical data and procedural specifications relating to the particular domain in order to increase productivity and make better decisions. It allows a cost-effective information exchange and a well-timed update of the information accessible in real time [4]. Accordingly, it significantly reduces time and error while attaining a comprehensive project improvement.

In a typical BIM workflow, a BIM project starts when a need for a building arises, architects with due consideration to customers’ needs and basic mechanical ideology, create a digital information model of the building using a BIM software with knowledge of the general geometry and the requirements that should be met in the building. All physical elements are modelled in this phase ensuring compatibility and relationships in all design parameters. This architectural model is then exported in a common data environment (CDE) such as industry foundation classes (IFC). CDE is defined as a common digital source of information for any given project that is used to provide access to the information for all the project teams. Each individual discipline imports the model and adds the information to the digital BIM platform related to that domain. So these models are updated as per the needs of each individual discipline differing in many important aspects from each other. All these updated models are exported to the original model which is ready for the construction.
The construction phase is started with this updated digital model. The sufficiently detailed model is used to automatically create all project drawings, ordering of materials and other construction documents [5]. It includes all data regarding every step of the construction process. Automation of various processes guarantees a significant saving of time reducing rework and errors. This complete BIM workflow is described in Fig. 2.

However, in reality, the extremely fragmented nature of the AEC industry, temporary project-based partnership, modern architectural designs and increasing complexity of the information involved are major factors hindering the successful adoption of BIM. The complete acceptance of BIM strongly depends on the quality of exchanged information and its use in the receiving applications. Extremely complex process of planning, design and construction of a built facility necessitates efficient communication between the diverse stakeholders in a given building project in order to work according to plan. A vast number of different companies and people come together for a particular project and only for the short duration of the projects. A wide variety of BIM software and tools are being used by involved professionals while working independently on their domain specific tasks available tools to deal with the project's specific needs during the entire life cycle of a building [6]. The siloed operation of these stakeholders hinders their collaboration. Exchange of information is not ideal: create a model in one software, export it to another and continue modeling. For instance, an architectural model imported by HVAC engineer should be able to used as a basis for energy analysis purposes. In practice, the project participants working on the BIM model need to manually re-enter a large amount of information and set certain new parameters along with the input data obtained from BIM.

2.1. Industry Foundation Classes

With a realization of importance of integration and seamless flow of information between various BIM tools, International Alliance for Interoperability (IAI), at present buildingSMART [7] international not-for-profit, open and neutral organization, in order to facilitate the whole AEC industry to improve the sharing of information all over the lifecycle of built facility, has developed an object-based, vendor neutral international standard (ISO 16739-1:2018) known as IFC. IFC short form for Industry Foundation Classes, provide freedom to all project participants to use the software tools of their own choice without thinking about the exchange of information with other professionals. IFC defines semantic information that is geometry as well as the properties of building objects and their relationships within BIM models. This encourages the sharing of information across diverse applications, which is a prerequisite for improving collaborative workflows in BIM environment. The IFC platform is sighted as one of the key driving force to overcome the inefficiencies of a scattered and fragmented industry.
BuildingSMART, committed to the creation and adoption of open, international standards and solutions for the industry, released first version of IFC in 1995 as IFC 1.0. Since then it is continuously improving the data model and adding new classes and properties with each new release. However, IFC 2x3 is most commonly used IFC schema for its wide coverage of support. To deal with the data sharing challenges and to ensure the efficient implementations of IFC models, buildingSMART has started certification process for trustworthy information exchange between software applications in real projects [8]. Software certification procedure provides confirmation for implementation of IFC standard helping software applications to ensure IFC consistency of data exchanges and the totality of information. Applications acquire the IFC-compliant label by going through a rigorous certification process. All IFC certified BIM software are proficient of writing, reading and sharing information with other software applications as per the norms laid down by buildingSMART. IFC-compliant applications can import IFC models, re-use intelligent information contained in other IFC-compliant tools and further export updated models as IFC files for coordination and re-use in other BIM authoring applications.

This is becoming ever more significant as different governments and government agencies are expecting the projects to be submitted in IFC format. For instance, in order to automate the code checking process, Singapore government has initiated the submission of building plans in IFC format and also in the USA the General Services Administration (GSA) [9], critical to successful integration of computer models in a building project mandated all building information to be furnished in IFC format.

IFC, receiving great attention, although very successful in providing a collaborative environment and have made significant progress in solving the information exchange issues to a great extent. No doubt, it is continuously developing, more than 200 software applications are already certified as IFC-compliant and generating and receiving data in IFC format. However AEC professionals are still facing numerous challenges when implementing IFC in their projects. Major elements lost parametric intelligence when IFC model is imported in various BIM applications. Geometry distortion, missing information and change in file size were reported while retrieving information through IFC file format. So the seamless flow of information among all stakeholders using IFC model is not a complete reality yet [10]. In practice, various participants working on the same project need to re-enter numerous data manually, make additions and set new parameters in addition to the input data obtained from IFC model.

The work revealed in this paper explores how efficiently BIM can be helpful towards sustainable construction by improving the integration among people involved in a building project. This work argues the reliability of using IFC file formats for storing and sharing of information in different phases of construction.

3. Related Work

The Information sharing and exchange is considered as one of the core factors of collaboration all the way through the building lifecycle. A variety of efforts from both researchers and industry have been devoted to addressing the problems related to the exchange of information between heterogeneous software tools based on IFC files[11]. For the past few years research community has shown a great interest for analysis of mapping between various design tools in a precise and reliable manner [11]. Round-trip testing, a particular form of import/export was adopted to tests the interoperability of an application with itself [12]. [13] developed EVASYS (EXPRESS Evaluation System), a tool designed to compare two IFC models. It was the first tool developed using C# to automate the count of the total number of matching instances. The tool used a third-party element, called the IFC Engine as a sub-component in the EVASYS system. IFC has been accepted as most widely used platform to store and share the building information among different professionals. However exchange of information using IFC models is not satisfactory. A widespread method to investigate the interoperability is by comparing various IFC files [14].
IFC files generated by three architectural software, were compared for interoperability performance evaluation [15]. Open standards play a vital role in sharing the building data to enhance communication and collaboration between different domains. These can be used by professionals even if not designed for that particular profession. IFC platform does not support the full exportation of certain typical proprietary data types which preserve application functions that mean, in a round trip test, IFC files cannot create the original file with complete of its description. So there will be loss of object information every time IFC file is imported or exported. [16] recommended to improve the quality of IFC interfaces mentioning it as the cause of incomplete mapping between native software file formats and IFC schema. [17] proposed a content-based automatic comparison tool, named IFCdiff, to identify dissimilarity between two IFC files. The proposed method, besides providing a complete analysis of the configuration and content for each IFC file, eliminate redundant IFC instances thus reducing the computational time.

4. Research Methodology

The BIM workflow described above laid down in section 2 necessities and set requirements for a framework for practical solutions for providing a collaborative BIM based environment to the construction industry. Upholding the model quality and consistency of data are considered as major challenges to this collaboration. Continuing development of IFC standards by buildingSMART are allowing the transformation of semantic information between various software applications who work together with their diverse domain specific tools. According to a comprehensive survey by buildingSMART, more than 200 software applications have abilities to import/export IFC data models. It has changed the conventional one-to-one direct data exchange process between diverse software applications based on native file formats (Fig. 3a) by sharing of a single model with all the participants (Fig. 3b).

However the comprehensive review of previous work suggested that structured geometric information exchange between various architectural applications based on IFC models cannot be blindly trusted. For the lack of guiding rules as regards the software usage and insufficient IFC interfaces, challenges the efficient collaboration among BIM authoring applications using IFC models. Issues related to IFC certification has always been a matter of discussion. IFC models are not being able to met end users expectations of seamless exchange of information in their software applications [18].
The work revealed in this paper explores how well the semantics of BIM models are preserved when information is exchanged through IFC files in different design tools. This work argues the reliability of using IFC file formats for storing and sharing of information in different phases of construction.

The evaluation criteria to investigate issues in the process of data import and re-export between heterogeneous software using IFC files can take different workflows. In a general workflow, known as round-tripping, a model is generated in software A and then exported as an IFC model, can be imported in software B or it can be imported back to the original software that is software A and again re-exported as IFC file without making any modifications. These import/export workflows are not only limited to an exchange of IFC models from one application to another BIM application [19]. Sometimes multiple creating and accepting BIM software are used. Several workflows involve the creation of model in single software application and exported to many applications and vice-versa. In other workflows IFC model is created in many applications and exported to a number of BIM applications. The purpose of these import/export workflows is to be able to compare the original IFC files to the exported IFC files. These workflows are important as the collaboration among industry professionals revolve around the quality and reliability of information exchanged.

Round-tripping workflow, where the BIM model is generated in single software, exported as IFC model and then this IFC model, without any modification, is imported back to the same BIM software and again re-exported in IFC format, is known as pure round-tripping testing. So there are two IFC files of the same BIM model. Re-exported IFC file is compared with the original IFC file, to evaluate that how much compatible a software tool is with itself over a wide scope of experiments. The pure round-trip workflow mainly focused on degree of restoration of native object types and semantic information required. These workflows are significant for collaborative environment. For instance, an architectural model is imported in a structural design application. Structural engineer use this imported semantic information for design and analysis purposes. After adding the information, the model is re-exported to the architect to update the original model.

In this study, the workflow similar to the export/re-export procedure described as above was followed to explore the strength and weaknesses of IFC file format. As a case study to explore the issues surrounding the utilization of IFC files for exchanging design model information between a variety of different BIM tools, two of the most common BIM authoring applications, FreeCAD and Autodesk Revit, have been evaluated. The criteria to select the tools were simply based on their popularity in AEC industry. One of these chosen software is open source software and second is a proprietary software. FreeCAD (M1 from now onwards) is a popular parametric 3D computer-aided design modeller used to create 3D models. It is most suitable for geometric design and most appropriate tool for professionals willing to be a part of BIM process. It is free of charge yet powerful software downloadable from FreeCAD website [20]. Second software used in the research is Revit Architecture from Autodesk. Revit (M2 from now onwards) is the most commonly used proprietary software (with three years free subscription for students), having powerful tools for architectural, structural and MEP designs helping project teams to produce simple, effective and better outcomes collectively. IFC file format is used to exchange the models in these software and results are examined in terms of information loss and geometry distortion.

4.1. BIM Model Preparation

As a case study for this work, a BIM architectural model was created in both the software that is one in each of tool M1 and M2. The test models were composed of several fundamental architectural elements such as beam, column, wall, slab, door, window and their attributes. The models were first saved in the original applications in native format as shown in Fig. 4 and Fig.5 and then exported as IFC models in IFC 2x3 coordination view format.
4.2. Round Trip Test
For performing round trip test, the exported IFC models were then imported back in the originating application and re-exported in IFC file format. Also the same IFC model from tool M1 was imported in M2 and exported in IFC file format without any modification. Similarly IFC model from M2 was imported in M1 and exported as IFC file. The workflow for the study is shown in Fig. 6.

![Figure 6 Workflow IFC data exchange between BIM software](image)

The original and exchanged IFC models were then examined to find how much information can be shared without data loss and distortion. Evaluation criteria includes investigation of overall information such as file size, type of entities, disparities in representations and the exact geometry of objects along with their relations from viewpoint of an end user. Several tools have been developed for comparing the exported and original IFC files in various research projects to be used in their own projects. Many of these tools were made freely accessible to be used by the community to carry out simple data analysis. These tools are categorised as graphic viewers and text based analyzers. Graphic viewers are used to inspect appearance of the model geometric information that can be inspected visually in an IFC file and to examine the hierarchical arrangement of building elements. Examples of graphic viewers are Solibri Model Viewer, BIM vision, Tekla BIMsight, usBIM.viewer+, IFC Viewer etc. The text viewers provide summary statistics of IFC models such as file size, type of entities, entity counts, style, syntax and structure and also the relations between entity instances for representing a building model. Some of the text browsers are IFC file analyzer, ifcdiff, IfcQuickBrowser, IfcOpenShell, DDS IFC Reader etc.

The examination commenced with a visual inspection of original and re-exported IFC files. BIM Vision and usBIM.viewer+ viewers were used for visual inspection of the models. Visual inspection is a simple and fast but important method to examine if the software were having problems in exporting...
the model or only reading it. Then IFC file Analyzer [21] was used to compare the semantics of all the IFC models. The IFC File Analyzer is capable of extracting complete information from an IFC file in terms of file size, number of entities and entity types and provides the summary of this information in an Excel file. It creates one main summary worksheet and one sheet for each type of entity processed in the IFC file [33]. The IFC File Analyzer examines single or multiple IFC files and generate the results of the analysis in a comparative worksheet.

5. Discussion

The building models for this simple experiment were modelled with two most commonly used architectural BIM software and exported and imported as IFC files. After the data exchange has been completed, with concentration on the examination of geometry exchange, IFC viewers and IFC File Analyzer were used to analyze the content of exported IFC files. Several restrictions were found in exchanging both object geometry information and other semantically significant data. The summary worksheets as shown in Fig. 7 (a) and (b), created by IFC File Analyzer unveiled a number of standard and non-standard entities along with their attributes. Fig. 7(a) presents the comparison of IFC file generated with M1 and Fig. 7(b) reveals the results of IFC files produced by M2.

![Summary worksheets form IFC file analyzer](image)

When importing IFC models, some software behave as a kind of black box. They can produce IFC files, but are not capable to receive IFC files [15]. This was a major issue faced in the experiment in which the building model created in M1 tool was imported in M2. An error window popped up (as shown in Fig.8) with a message that no building elements are found in the file. So no IFC file could be exported from tool M2, so a large portion of the experiments was incomplete.

Although no major issues were noticed in the visual inspection of the models in IFC viewers, the quantity representation in Fig. 7 revealed a number of issues of geometry distortion and loss of information in the IFC file contents. Each data exchange combination resulted in considerably dissimilar geometry interpretation. A comparison of file size and number of entities were not appropriate indicating that model exchange with dissimilar software interfaces marks the diversified methods of creating the models and thus increasing/ decreasing the file size and number of entities.

For export and re-export of IFC files from software M1, the file size was two times and number of entities was increased by 50%, respectively.
entities increased three times. This change could be attributed to the needless increase in the entities such as IfcFaceBound, IfcPolyLoop and IfcCartesianPoint and so on.

Figure 8 Error window in Revit

Although no major issues were noticed in the visual inspection of the models in IFC viewers, the quantity representation in Fig. 7 revealed a number of issues of geometry distortion and loss of information in the IFC file contents. Each data exchange combination resulted in considerably dissimilar geometry interpretation. A comparison of file size and number of entities were not appropriate indicating that model exchange with dissimilar software interfaces marks the diversified methods of creating the models and thus increasing/decreasing the file size and number of entities.

For export and re-export of IFC files from software M1, the file size was two times and number of entities increased three times. This change could be attributed to the needless increase in the entities such as IfcFaceBound, IfcPolyLoop and IfcCartesianPoint and so on. Although appearing larger in size, many instances are missing in it. The core missing instance is IfcExtrudedAreaSolid in this case. For import of IFC model from M2 to M1, the major issues were with transfer of material layers and shape representation of objects as can be seen in summary worksheet (Fig. 7 b) This could have happened because the different Architectural BIM software use different ways of representation to create the objects. Mainly three types of geometric representations are used to generate the objects which are IfcExtrudedAreaSolid (Swept Solid Representation), IfcFacetedBrep (Boundary Representation Method) and IfcShellBasedSurfaceModel (SurfaceModel Representation). Large discrepancy between the IFC exported files, even for the same architectural BIM software, is visibly apparent. The IFC schema does not support the export of some proprietary data types that sustain some particular application functions. Unable to export these instances, an IFC round tripped file is not capable of mapping the original application data, thus some characteristics will no longer work.

6. Conclusions
The study has been capable to conclude that seamless sharing of information among BIM authoring tools can help AEC industry to achieve the goals of sustainable construction by lowering project cost, construction time so on. Various what if scenarios can be considered at the initial stages of the construction phase. The successful, performance of building projects requires a planned and effective collaboration between all stakeholders. The growing expansion of BIM authoring tools has to be estimated regarding their situational fitness of information exchange in building projects. The sharing of information among different BIM authoring tools is not simple or straightforward due to complex illustration and reliability issues in the process of information. The study shows that the adoption of BIM can be efficiently used to achieve sustainable construction by enhancing the quality of information delivery, better collaboration and improved building energy analysis.

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