# Interoperability Assessment for Building Information Modelling

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**Abstract.** The construction industry in its heterogeneity has a need for better communication and process coordination among stakeholders. This lack of coordination is due to barriers in interoperability in strategic, conceptual and technological perspectives. Interoperability is the ability for agents to communicate and exchange data, information and knowledge. Around this definition, literature suggests that Building Information Modelling (BIM) will play an important role in the development of interoperability in the Architecture, Engineering and Construction (AEC) industry. Considering that barriers in interoperability can cause difficulties in the AEC industry (such as design overlapping, coordination issues and many kinds of financial loss), the need for a specific method and tools to assess the level of maturity in this field was perceived. This paper provides an approach to assess interoperability in the AEC domain. It is based on the concerns suggested by the main interoperability frameworks found in literature, such as the European Interoperability Framework (EIF). The interoperability assessment is then structured using the value levels (communication, coordination and cooperation) proposed by Grilo and Jardin-Goncalves [1] as maturity levels. The AEC attributes were then formatted in a multi-criteria decision making structure, AHP (Analytic Hierarchy Process), from which specialists gave their opinion through a questionnaire to determine the perceived level of interoperability. The assessment and diagnosis stage of the research led to the conclusion that data interoperability is still the biggest issue, so a new method to assess interoperability between software and formats is described as a verification experiment, highlighting the main barriers in BIM.

## Introduction

The AEC industry has some unique characteristics, which can lead to some special needs in communication among stakeholders. This communication must happen properly in all the stages of the building lifecycle (conception, design, construction management etc.) [2,3]. One of these characteristics is that the AEC industry produces unique products. Every building is a singular product; none is the same as any other. This means that every building needs its own specific design and management that need to be conducted in a practical and fast manner. Another characteristic is that the AEC industry is heterogeneous. In one project there will be architects, structural designers, contractors and engineers from many different specialties (civil, mechanical, hydraulic, electric, etc.). This two specific characteristics lead to a great need for efficient interoperability among the agents and entities in AEC environment. The lack of interoperability can cause a series of compatibility problems that sometimes will only appear in the execution stage. The plumbing system overlapping with the structure and windows and doors overlapping with electrical fixtures are some examples that illustrate this scenario [1].

According to the EIF (European Interoperability Framework) [2] interoperability means the ability to exchange data and allow information and knowledge share in business processes, through information and communication technology (ICT). To address this issue, Building information Modeling – BIM has emerged as an important technology to aid the AEC industry to improve interoperability [1]. BIM is a process that generates building models through software; these models should include data from all the areas involved in the entire lifecycle of the building. However,

according to Ibrahim [3], in the AEC industry the difficulties in interoperability among platforms can be a barrier to the adoption of BIM by the market. This fact could lead to a vicious cycle: BIM must be adopted to improve interoperability, however interoperability among BIM platforms doesn´t seem to be in a stage where it is good enough for the adoption of BIM.

In order to face this issue, a need for a method to assess BIM interoperability maturity was perceived. To achieve this, a research was elaborated focusing on interoperability in AEC/BIM. For this study a foundation on the literature was established. A list of attributes was created based on those proposed by Building SMART, and they were mapped into Chen´s [5] interoperability framework. These attributes were reviewed and organized in Grilo and Jardin-Gonçalves [1] proposed value levels for BIM interoperability (Communication, Coordination and Cooperation).

## Building Information Modelling

Building information modelling, also known as BIM, is defined by Eastman *et al*. [6] as a modeling technology and associated set of processes to produce, communicate, and analyze building models. BIM systems are Object Oriented CAD systems. This means that objects are understood by the system as such, not only containing geometric information. For example, in a 2D CAD system a door is represented by a set of lines and written information. In a BIM model this door is represented tridimensionally, containing characteristics such as material, supplier, cost and other elements [7]. Also, this door is considered by the system as such, and must be positioned on a wall of the model, as a real door would. This is called building object behavior.

All this leads to an integrated model, meaning that if something is altered in the 3D model, all documents (such as drawings and spreadsheets) will be altered automatically as well. These characteristics will lead to an integrated model, in which all information of the building´s lifecycle must be contained. This model should contain all information of the building´s lifecycle, including architecture, structural, electric, mechanical, plumbing and all areas involved in the building process [6,7].

BIM is not widely adopted yet, due to many different barriers. These barriers are concerned with either technical or human issues. The biggest human issues are the lack of understanding of what BIM is exactly and the lack of BIM knowledge and preparation to use specific software. The technical barriers are the difficulties to choose the correct time, project, and systems to start implementing BIM, as well as the lack of interoperability perceived by the users among platforms [3].

## Interoperability for BIM

According to the European Interoperability Framework [2]: "Interoperability means the ability of information and communication technology (ICT) systems and of the business processes they support to exchange data and to enable the sharing of information and knowledge". This EIF's definition can be applied to the construction industry and BIM, as well as the interoperability concerns, described by Chen [5]. There are four interoperability concerns described in literature as indicated in Fig.1:

- Business: It refers to interoperability in the organizational and company levels. This relates to BIM in the sense that the use of BIM needs to become a strategic action in the company, in which all stakeholders need to be involved in order to communicate, understand and share information among agents such as architects, structural engineers, electrical engineers, etc.
- Process: Is concerned with the requirements needed to align the process and make them work together [5,8]. By using BIM instead of convention CAD, companies not only change their way of representing their designs, but it alters the whole process, from the earliest stages in creating throughout the whole design and construction processes.
- Service: Service interoperability is the ability of an enterprise to aggregate, register and consume services of external sources [8]. It aims to make all services from different companies work together. In BIM this concern is connected to communication concerning the

suppliers in order to receive detailed information about products or manage income and outcome of external resources, for example.

- Data: This concern is related to the need for different systems and platforms to work together. It describes the ability of multimedia content, documents and digital resources to be available, usable and comprehensive by all stakeholders [5, 8]. In this case BIM is concerned with the formats in which the information is distributed, for example, open formats and proprietary formats.
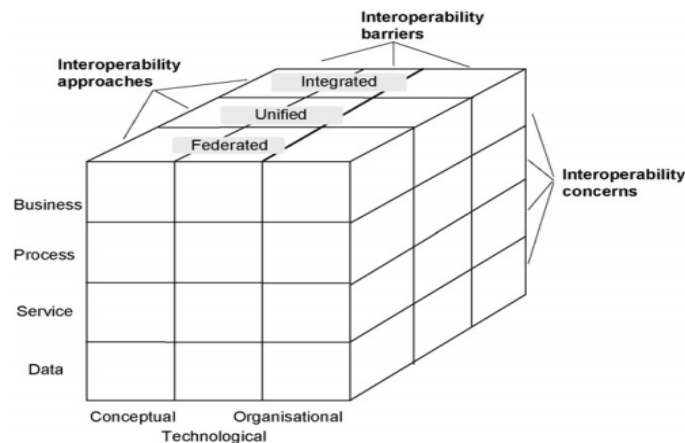


Fig. 1. Enterprise interoperability framework [5]

Chen´s [5] framework also divides interoperability barriers in Conceptual, technological and organizational, as shown in Fig. 1. Interoperability levels are also established (Integrated, unified and federated). In order to better understand BIM interoperability, specific interoperability value levels were determined [1] as shown in Fig. 2. These values are strongly related to how can BIM interoperability contribute to a companies' competitiveness.
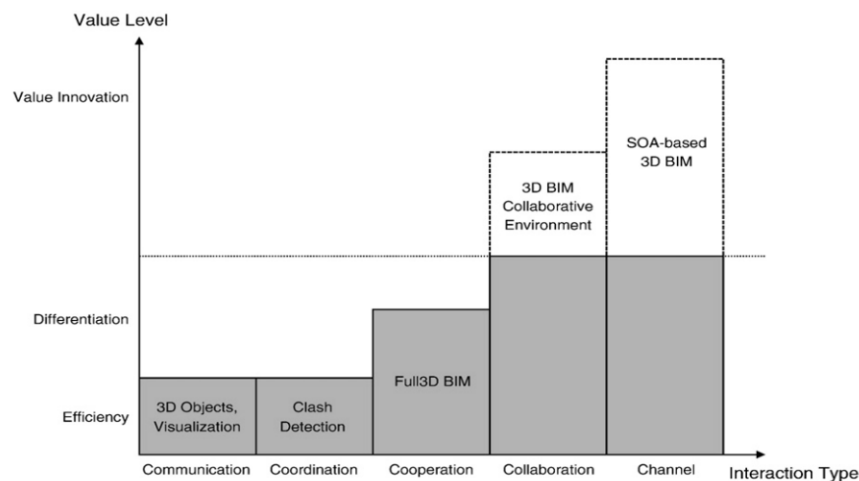


Fig. 2. Interoperability value levels [1]

The first value level of BIM interoperability is *communication*. In this level, the main concern is with the use of 3D modelling. This relates to interoperability in the sense that 3D visualization allows much better understanding, henceforth, better communication of the design. The second level is called *coordination*. In this level, clash detection, overlap avoidance, etc. are expected. After this, full 3D BIM is expected on the third level, also known as *cooperation*. This means that there should be supply chain visibility, construction and energy simulations, cost prediction, etc. This level is focused on obtaining advantages by sharing work among agents. The next level, *collaboration*, assumes BIM

collaborative environments. And the fifth and final level, *channel*, expects an automatized environment permeated in the whole process, including production.

The group known as Building SMART seeks to create solutions for BIM interoperability, and created the IFC (Industry Foundation Classes). IFC is an open format for BIM platforms. Building SMART [4] has set a roadmap for BIM interoperability evolution, as seen in Fig. 3. These characteristics were used as a foundation for the attributes on this study´s AHP structure, described later on.
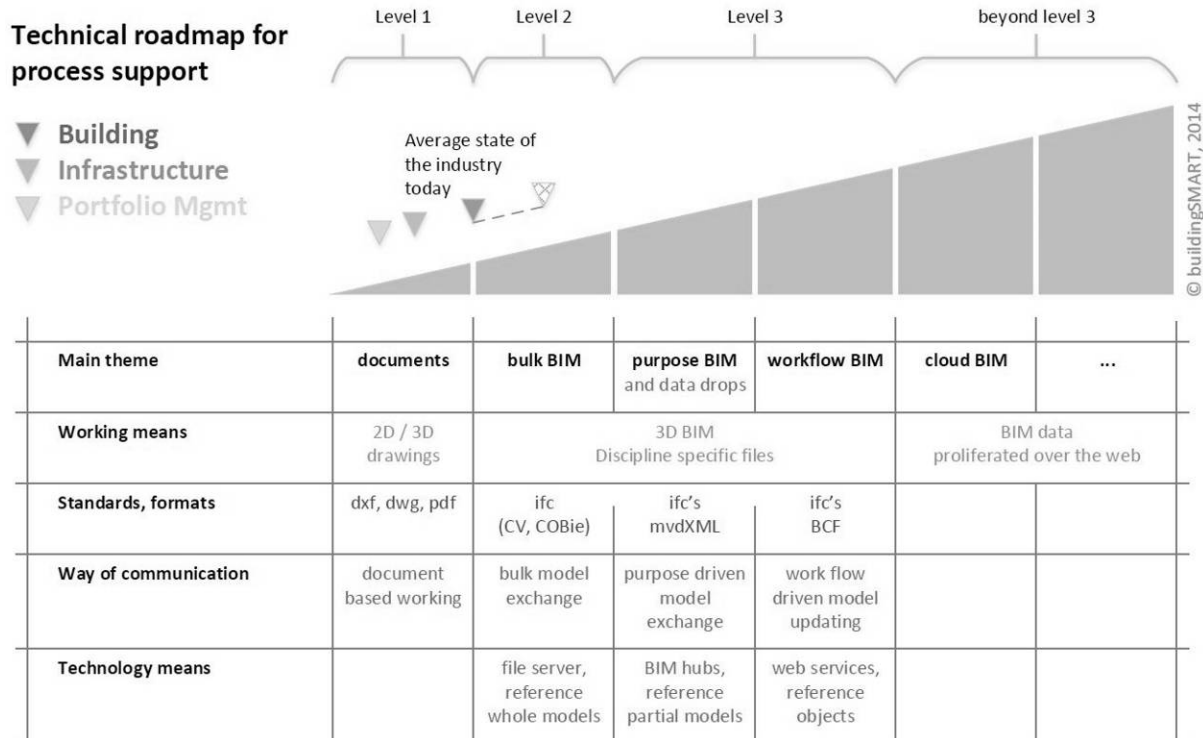


Fig. 3. Roadmap for BIM interoperability [4]

**Interoperability Assessment Methodology**

In order to develop the interoperability assessment in BIM domain, a methodological structure is proposed consisting of four methodological steps shown in Fig. 4. The *first step* consisted of a bibliographical research to collect characteristics and attributes for BIM interoperability, according to the levels of development and the corresponding interoperability concern. The levels proposed were related to the first three levels of the interoperability value levels described previously (Fig. 2).
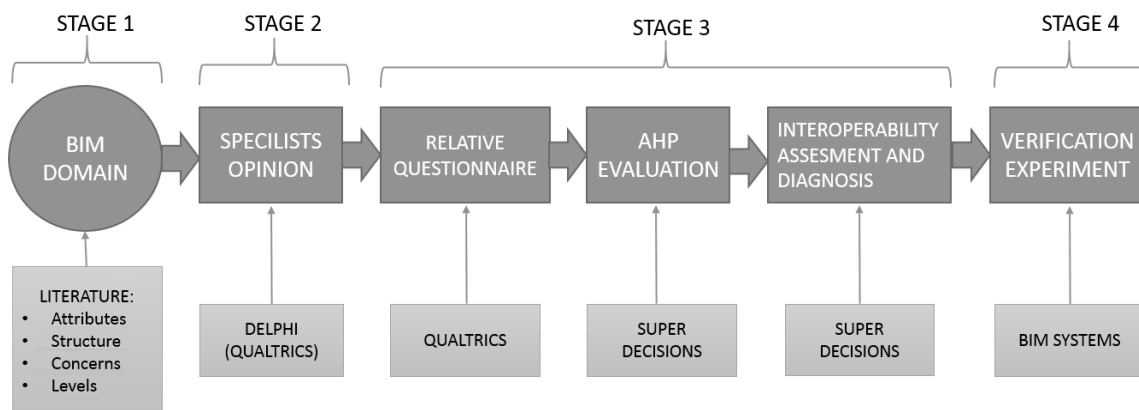


Fig. 4. Methodological structure.

The structure is shown in Fig. 5. The objective of the research is to determine where BIM interoperability stands, according to the perception of specialists in the area. This will allow a perception on in which area further study is needed.

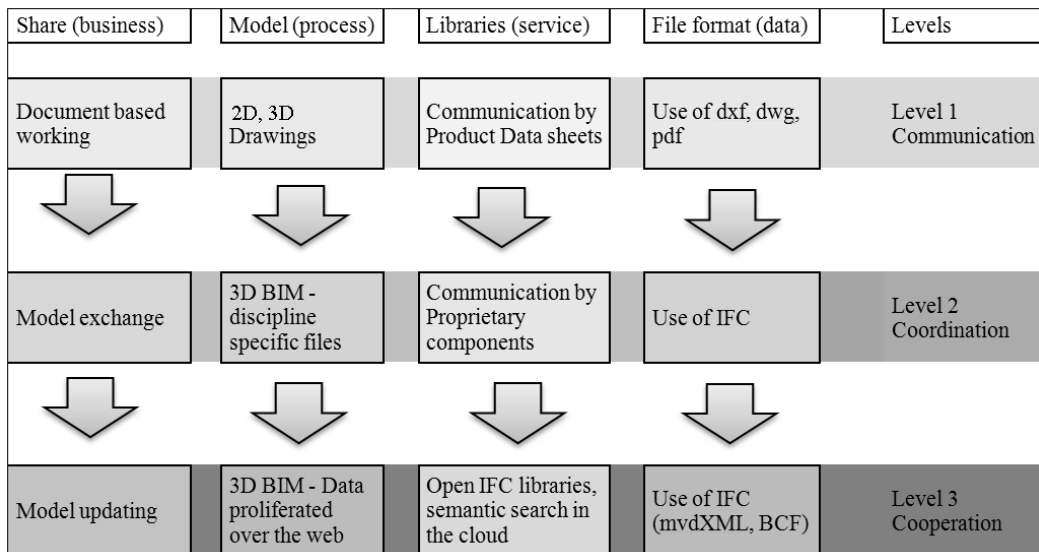| Share (business) | Model (process) | Libraries (service) | File format (data) | Levels |
|---|---|---|---|---|
| Document based working | 2D, 3D Drawings | Communication by Product Data sheets | Use of dxf, dwg, pdf | Level 1 Communication |
| Model exchange | 3D BIM - discipline specific files | Communication by Proprietary components | Use of IFC | Level 2 Coordination |
| Model updating | 3D BIM - Data proliferated over the web | Open IFC libraries, semantic search in the cloud | Use of IFC (mvdXML, BCF) | Level 3 Cooperation |

Fig. 5. Interoperability attributes and structure for BIM

In the *second step*, specialists confirmed the order, characteristics and attributes for each level in defined rounds of Delphi method. The Delphi method is used to gather the opinions of specialists on a given subject, preferably leading to consensus, but not necessarily [9]. Some small changes on the structure and attributes were made according to the expert's suggestions.

On the *third stage*, an AHP survey was conducted. This method was chosen due to its value in decision making, valuing specialists opinion. This method shows effiency in many different situations, such as ontological research [11]. A relative questionnaire, conceived from AHP requirements and structure, was sent for specialists to compare the attributes indicated in Fig. 5. Their relative perception and evaluation are aligned to perceive their views on how the state of industry is at the moment.

The AHP method, supported by the questionnaire, leads the collaborators to perform a relative pairwise comparison between the attributes by their perceived degree of importance [10]. The adoption of this process enables the possibility to consider the uncertainty of the collaborator that replied. This uncertainty is then verified by the degree of inconsistency obtained. In some cases, this degrees may suggest the need to review the respondents´ final comparisons. The specialists that participated in the survey were academics with large knowledge on BIM, and some had experience in the industry as well. After the data was collected and analyzed, percentages were calculated according to the views of the specialists, as shown in Fig. 6.
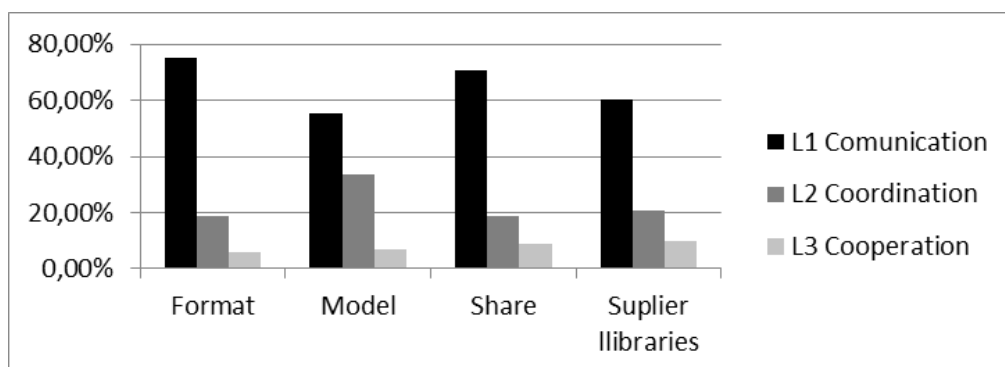


Fig. 6. Results from the survey.

The study shows that the format (data) concern is the least developed, and is still mainly in level 1. This is probably one of the biggest barriers to BIM interoperability, because systems must be able to read files in order for an effective interoperability. It is also the concern in which level 3 is furthest from being implemented and used. The share concern shows low development as well, probably due to the fragmentation in the construction industry. The modelling concern was perceived as the most developed. This is probably due to the fact that parametric modelling is very practical, becoming more attractive to users. Suppliers are not far behind, developing libraries for their products. Fig. 6 shows that, according to the specialists' perception, level 1 is still predominant. This means that BIM implementation is only at its beginning. While some companies are trying to move up to level two, level 3 is still far from implementation.

The results from this interoperability assessment showed that there is a perceived difficulty in the data (format) area. This led to a fourth and final stage, where it was perceived that a verification experiment was needed.

**Verification experiment for data interoperability among BIM software**

This second part of the study describes digital data exchange experiments to verify interoperability among BIM platforms. The partial results show that there is the possibility of interoperability, however interoperability with degraded quality. This means that system are functioning, but with an imperfect data set [12].

The study was conducted using cast-in-place concrete structural models, because such structures present unique challenges for modelling, such as being monolithic (there is no physical separation of a beam and a column for example), the need for intricate reinforcing bars detailing, use of specific concrete type, etc. [12]. A model of an entire building structure was used, as well as models of structural entities isolated from the rest, so they could be analyzed individually, as seen in Fig. 7.
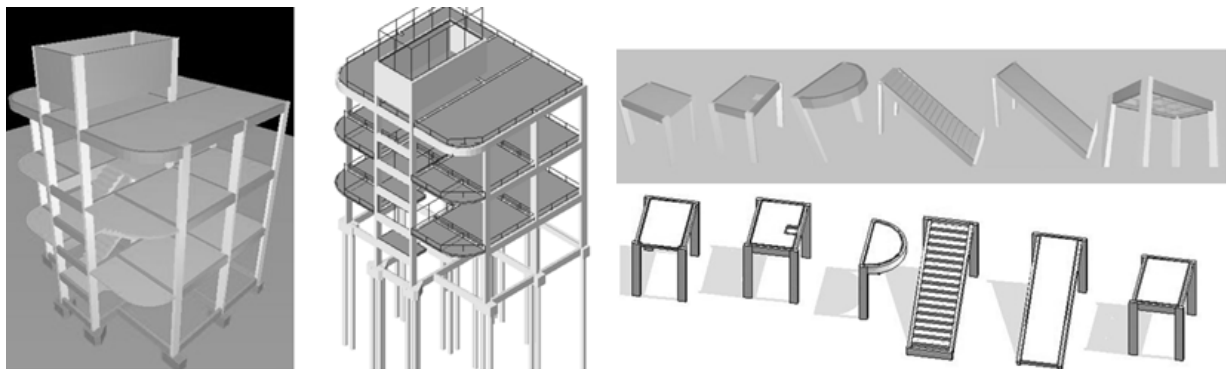


Fig. 7. Examples of models generated in Software A and Software B.

The most difficulties met with geometry were related to sectioning the objects. Cast-in-place concrete structures are monolithic, but BIM systems have big difficulties treating it as such. For example: a beam does not end when it meets a column, and neither does the column end when it meets a beam, so the volume in the intersection belongs to the beam as well as to the column. This generates a second problem, because sectioned elements are assigned different GUIDs (genuine unique identifier) as well. The errors in the identifiers transferences were mainly due to the geometry errors. Systems have also shown some difficulties dealing with curve and other complex geometry. Finally, one of the biggest concerns is with the reinforcing bars and detailing. Detailing is an important part of the processes, and hardly any information was transferred properly.

In the experiment, structures were modelled in two commercial systems, and exported to IFC. The IFC files were then opened by the software that generated the file, the other system and then by an IFC

model viewer, creating a total of six transfers to be analyzed, as shown in Fig. 8. The use of the IFC model viewer was important to verify if the software were having difficulties exporting the model or just reading it. For each structural element, four characteristics were analyzed through visual inspection: GUID, placement, geometry and material. The structural elements studied were: beams, columns, slabs and foundations. If the characteristic was transferred perfectly, it received a score 1, if the characteristic was partially transferred, it received a score of 0,5 and if it was not transferred, it received zero.
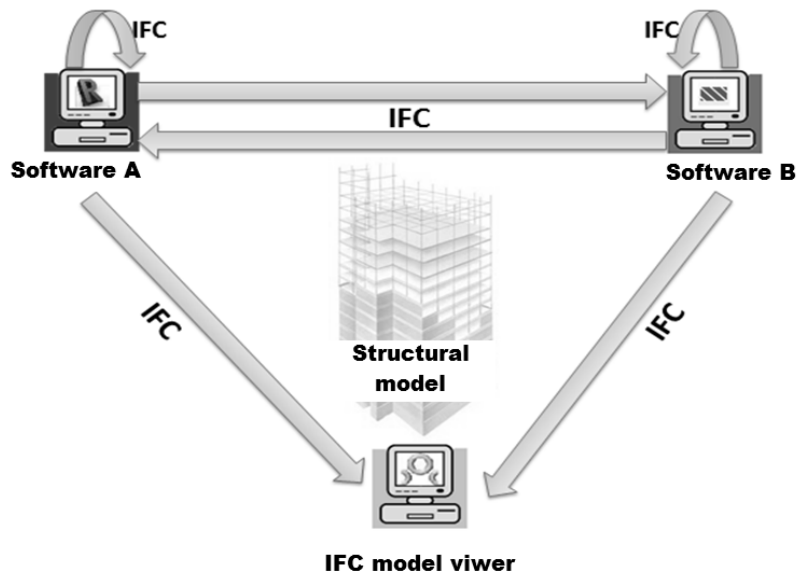


Fig. 8. Model transfers

The results show us that the biggest problem lies with the material characteristics, as shown in table 1. This probably happens because including material information in the objects is a somewhat new concept in the AEC industry. Before BIM, models had extensive geometry, but all material information was indicated in writing.

Table 1. Results from the experiments.

| OBJECT | GUID | PLACEMENT | GEOMETRY | MATERIAL | TOTAL |
|---|---|---|---|---|---|
| COLUMNS | 0,583 | 0,667 | 0,500 | 0,383 | 0,537 |
| FOUNDATIONS | 0,583 | 0,667 | 0,583 | 0,250 | 0,522 |
| BEAMS | 0,618 | 0,667 | 0,513 | 0,538 | 0,583 |
| SLABS | 0,583 | 0,633 | 0,578 | 0,525 | 0,580 |
| TOTALS | 0,592 | 0,658 | 0,545 | 0,425 | 0,555 |

**Conclusion**

Building information modelling is expected to play an important part on interoperability for the AEC industry according to the views in the literature. However, the specialists see further need for development for interoperability to reach a level where BIM is implemented and working fully (or at least with most agents connected). The specialists perceived that BIM is not regularly used in the AEC industry yet, specially on the data (format) and business (share) concerns. This means that further study on interoperability concerns will be needed, with a special focus on how to improve IFC files, in order to improve interoperability in data, which showed the least developed of all four concerns. In order to improve data interoperability through IFC, the special aspects of the AEC industry must not be taken for granted in the development of the systems and their ability to generate IFC files. A special

attention must be given to materials, geometrical characteristics and detailing to improve IFC interoperability in cast-in-place concrete structures.

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