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DATA INTEROPERABILITY ASSESSMENT THOUGH IFC FOR BIM IN STRUCTURAL DESIGN – A FIVE-YEAR GAP ANALYSIS

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Abstract. In the last years the AEC (Architecture, Engineering and Construction) industry has been influenced by the development of Building Information Modelling (BIM). With the creation of complex systems, the need for efficient interoperability arises. Based on a study of BIM interoperability dimensions and its levels, this research presents an interoperability assessment of BIM system in the structural domain, especially considering cast-in-place concrete structures, since they present some special challenges for system interoperability. This assessment was conducted by experiments that imported and exported structural models and structural elements through a non-proprietarz standard for BIM models (IFC- Industry Foundation Classes). The experiments were conducted twice, with a five year gap from each other, so the evolution of the interoperability could be assessed as well. The results showed that some special characteristics must be considered in order to achieve efficient interoperability for cast-in-place concrete structures – these structures are monolithic and they have reinforcement steel bars that need detailing. Also, the research showed that in the five-year gap there were evolutions in interoperability, like in object identifiers, which had a considerable improvement. However, some of the major problems remain, such as overlapping of structural parts.

Keywords: interoperability assessment, building information modelling, BIM, industry foundation classes, IFC, AEC industry.

Introduction

The AEC industry commonly presents some individualities, which may lead to distinct needs in communication between stakeholders and companies. This communication needs to happen correctly in all the phases of the lifecycle of a building – (i) planning and design, (ii) construction, (iii) operation, (iv) repair and maintenance and (v) demolition. Each of these phases requires different semantics and workflows. One of these unique characteristics is the fact that the AEC industry creates unique products. Every building and its construction is a singular product, different from any other. Because building models require different semantics for different workflows over a project's lifecycle, the communication in all the phases of the lifecycle of a building needs to happen correctly (Venugopal *et al.* 2015; Wong, Zhou 2015).

This particular scenario amongst other industries means that all buildings need their own specific management and design to be conducted with efficiency and effectiveness. One more characteristic is that the AEC industry is not homogeneous in terms of the involved actors. In one single project there will be architects, engineers from several specialties (civil, structural, hydraulic, mechanical, electric, etc.) and contractors. In addition, the elaboration of a construction project is highly collaborative, and besides the fact that they usually comprise several areas, these professionals are spread in offices that use different software and platforms. These specific characteristics lead to a pronounced necessity for efficient interoperability between the entities and agents in the AEC environment (Gu, London 2010).

The ISO/IEC 33001:2015 Standard defines interoperability as "the ability of two or more systems or components to exchange information and to use the information that has been exchanged". Many efforts have been made to address interoperability barriers, and the exchange of information between the various disciplines of the AEC industry is still one major problem (Yang, Zhang 2006). The inefficient or even lack of interoperability may cause several compatibility and clash problems that occasionally may only become evident during the execution stage. The electrical system intersecting doors and windows or the plumbing overlapping with beams or columns are a few examples that exemplify this scenario (Grilo, Jardim-Goncalves 2010).

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To aid this process in the AEC industry, Building information Modelling – BIM was created and has been developed as an important technology to support interoperability in this area. BIM is a process in which building models are created through software; data from all the sectors involved in the lifecycle of the building should be included in the models. However, the main barriers to the adoption of BIM by the market are the difficulties in interoperability among platforms (Grilo, Jardim-Goncalves 2010; Muller *et al.* 2015). This fact leads to a vicious cycle: interoperability between BIM systems doesn't seem to be in a stage where it is satisfactory enough for the adoption of BIM, and in turn BIM must be more widely adopted to in order for interoperability to be improved.

Studies show expenses of 15 million dollars with losses derived from problems concerning the lack of interoperability in the BIM scenario (Venugopal *et al.* 2015). The study of Liu *et al.* (2016) points to the same problem, since many structural engineers often adopt computational and structural modelling software with different formats from BIM and IFC standard. In this regard, Hu *et al.* (2016) advocate that inadequate integration and interoperability continue to cause an economic burden and are often considered key factors for the initial resistance to new technology in project design.

To better address interoperability issues in AEC/BIM, literature points to a need for specific studies on interoperability influence factors and assessment methods (Grilo, Jardim-Goncalves 2010; Jeong *et al.* 2009; Muller *et al.* 2015). With this scenario in mind, the research described in this paper is structured as follows. In Section 1, the background for the research is established, and based on the literature, a process map for cast-in-place concrete structure design companies was developed in a scenario without BIM. This processes map showed that many stages in the design process were focused on clash detection and similar activities. In order to improve this scenario, BIM is proposed as a tool in a new process map. However, for this to become possible, the need for interoperability among platforms is necessary. So experiments focusing on IFC file sharing were developed, to verify whether using BIM as a repository for building design and file sharing was possible or not in the cast-in-place concrete structure domain. The methodology for these experiments is described in Section 2, and the results are presented in Section 3. Finally, conclusions for the experiments and research perspectives are presented.

1. Background and related works

1.1. BIM interoperability

According to the European Interoperability Framework (EIF 2004): "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 used in the AEC industry as well, especially through BIM.

In order to characterize an evolution of BIM interoperability, levelling models are proposed, as shown in Figure 1. These values levels express how interoperability through BIM can contribute to companies' competitiveness. Communication is the first and more basic level. In this structure, the main concern is with the use of 3D modelling. This is because 3D visualization allows better understanding, henceforth, better communication of the design. Coordination is the second level. In this stage, users are able to perform clash detection, overlap prevention, etc. The third level is known as cooperation. In this case, full 3D BIM is expected, as well as cost predictions, supply chain visibility, construction and energy simulations, etc. This level is focused on obtaining advantages by sharing work among agents. The fourth level, collaboration, assumes BIM use in collaborative environments. And the fifth level, channel, expects automatized environments permeated through the whole process, including the production stages (Grilo, Jardim-Goncalves 2010).

Chen *et al.* (2008) interpret interoperability through three axes: concerns, barriers and approaches. Approaches could be understood as interoperability levels. This means that interoperability can be in a level where it is considered integrated, unified or federated. Interoperability barriers can be conceptual, technical or organizational. This means that there is more to interoperability then the concerns related to software and technical issues. In order for interoperability to occur properly, not only technological issues should be solved, but also processes must be aligned and organizations must commit to interoperability.

Finally, authors divide interoperability concerns in four groups (concerns) and four levels. These levels can be linked to Building smart's guidelines and specific documents for better interoperability in the AEC industry (Building Smart is an international agency concerned with innovation and interoperability in the AEC industry, and will be discussed further on). Figure shows four interoperability concerns described in literature (Chen *et al.* 2008), that can be related to BIM dimensions, as described:

– Business: is concerned with interoperability in the strategic and organizational levels. This correlates

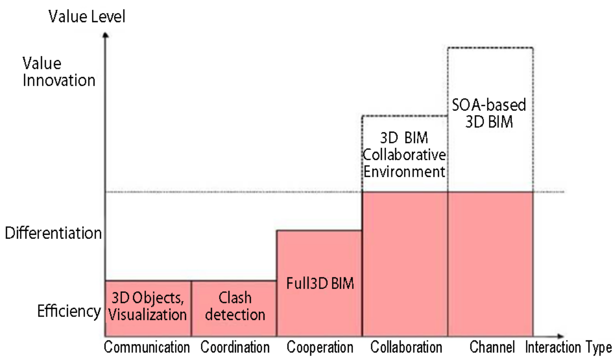

Fig. 1. Interoperability value levels (Grilo, Jardim-Goncalves 2010)

to BIM because the use of BIM is usually a strategic action in the company. Stakeholders need to be involved in the adoption process.
- Process: is related with the requirements necessary to align the processes for construction, design, and operation. By using BIM instead of traditional 2D CAD, companies change not only their way of designing, but it alters the whole process of building and operation. This is strongly related to Building Smarts' IDM – Information Delivery Manual, which formalizes the processes throughout the construction industry (Eastman *et al.* 2008).
- Service: service interoperability is the concern of an enterprise to aggregate, register and consume services of external sources. It focuses on the need to make all services from different companies work together. In BIM this is represented by the role of suppliers that need to provide detailed information about their products. This is also strongly connected to a Building smart document. In this case, it is the IFD (International Framework for Dictionaries) or BuildingSMART Data Dictionary (bSDD). Since suppliers need well-established definitions and ontologies for a better interoperability in the AEC industry. Also Rezgui *et al.* (2013) point that a big barrier to BIM adoption is the fact that agents in the service field (clients, designers and contractors) are still using 2D or paper-based files.
- Data: this concern refers to the need for different software, platforms and systems to work together. Multimedia content, digital resources and documents need to be usable, available and comprehensive by all stakeholders (Eastman *et al.* 2008). This concern is addressed by Building Smart through their open format, the Industry foundation Classes (IFC).

The levels in Figure 2 are based on the interoperability value levels (Grilo, Jardim-Goncalves 2010) and Buildings Smart's roadmap to interoperability (2014). The concerns described by Chen *et al.* (2008), form the vertical axis. This connection between both proposals can be described as a path for improved interoperability in the

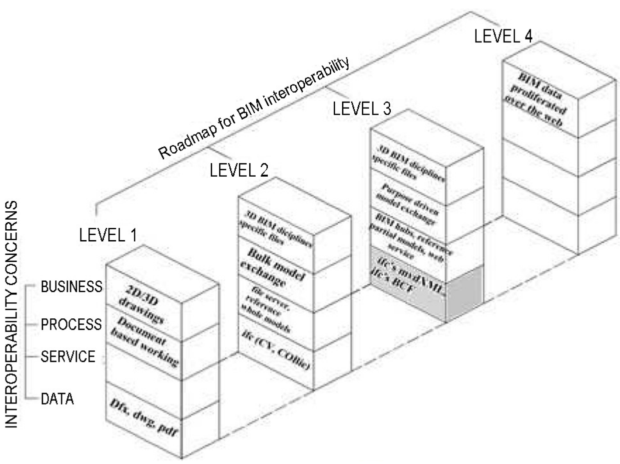

Fig. 2. Roadmap for BIM interoperability

AEC industry (Muller *et al.* 2015). Considering the figure described, it can be observed that the research developed in this paper is currently located in the highlighted box – IFC concerns for data interoperability – currently on the second level.

Also, further literature considers three interlocking fields of activities pertaining BIM, instead of the four enterprise interoperability concerns described in Figure 2. The first field is the technology field, which is related to the development of software, hardware and systems. Next, the process field is related to procurement, design, construction, manufacture, use, management and maintain of the structures. Finally, the policy field gathers tasks focused on delivering research, preparing practitioners and minimizing conflicts in the AEC industry. This study is located in the intersection of the policy field, since it aims to develop interoperability aiming to minimize data conflicts, and the technological field, considering its relationship to software development through IFC data files (Venugopal *et al.* 2012).

1.2. Building smart's interoperability standard for BIM

BIM systems are one sort of object oriented CAD. This means that, for example, a wall is perceived by the system as an object with the properties of a wall, such as thickness, height, length, as well as non-geometric characteristics, such as cost, material, suppliers, etc. These characteristics are Building Object Behaviours (BOB). This requires special cares and concerns with interoperability, since the information of the objects must be transferred correctly to agents involved in the design and construction processes. BIM is also a kind of parametric modelling and can be distinguished from CAD modelling by these characteristics (Lee *et al.* 2006):
- Users can manipulate and generate shapes, add constrains and new parametric relations. Also, these shapes may be altered by editing the values in the pre-defined parameters.
- A parametric system should use 3D modelling, since 2D is not sufficient to represent a complex model.
- Such systems should be object-based and feature-based. These objects can be constrained to each other if necessary.

These inefficiencies in interoperability can lead to rework, mismatched information, uncertainty and insecurity about the reliability of the data. Faced with this scenario, professionals in the AEC industry created the International Alliance for Interoperability (IAI) – current Building Smart, which aims to promote innovation and interoperability between architecture, engineering and construction software. To ensure this interoperability Building Smart developed Industry Foundation Classes (IFC) (Skibniewski, Zavadskas 2013). The IFC is a neutral standard, and its main goal is to standardize the classes of object-oriented systems in an open format, so that multiple applications can use it to share data (Build-

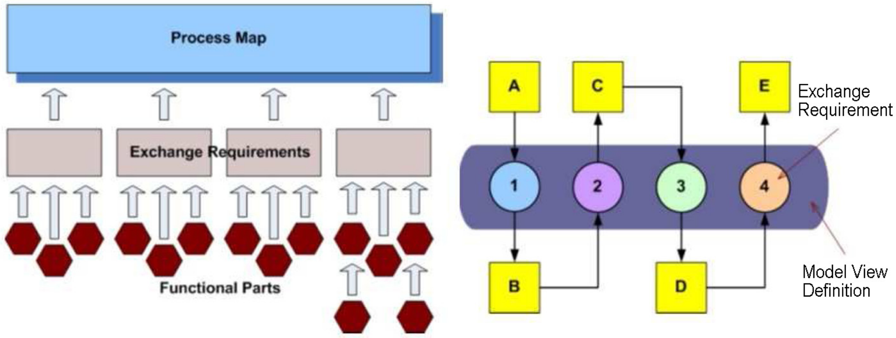

Fig. 3. In the right process maps, exchange requirements and Functional parts are shown. In the left the schema for model view definitions can be seen (Wix, Karlshoej 2006)

ingSMART 2014). IFC is also registered in the International Organization for Standardization. Due to this fact, IFC is widely used in architecture, engineering, construction and facility management (Lee *et al.* 2016a, 2016b).

In order to aid the improvement of interoperability in BIM platforms, BuildingSMART develops four main document types. The first document is the IDM – Information Delivery Manual, a BuildingSMART's standard for processes. It defines details of how, when and what kind of information should be supplied by which agent and at which stage of the project (Wix, Karlshoej 2006). The IDM is comprised of functional parts, exchange requirements and Process Maps. The requirements appear in detail in the Information Delivery Manual (IDM), which contains implementable specifications for software vendors (Lee *et al.* 2016 a). A functional part describes information as a small set of IFC information needed to perform a certain task. Exchange requirements are the sets of model information applied to each case, and the process maps organize these sets of information, as shown in Figure 3 (Wix, Karlshoej 2006).

As a second artefact, Model View Definitions (MVDs) are related to software requirements for IFC implementation. It formalizes the information exchange processes for systems, as shown in Figure 3 (BuildingSMART 2014; Wix, Karlshoej 2006). The MVDs map the system import/export features and IFC. This binding correctness must me checked by developers and users. Some studies have developed automatic checking; however, this automatic checking does not apply to all cases, especially considering heterogeneous industry as the AEC field, so users may have to resort to manual checking of MVDs and IFCs (Lee *et al.* 2016b). The third document is the IFD (International Framework for Dictionaries) or BuildingSMART Data Dictionary (bSDD). It is a dictionary of terms for libraries and ontologies (Wix, Karlshoej 2006). Finally, as the forth artefact, Industry Foundation Classes (IFC) represents a neutral and open standard for BIM. It may be used to exchange information between different systems and platforms (BuildingSMART 2014).

The development, implementation and deployment of BIM standards should follow three basic stages. In the first stage, developers elicit knowledge from the industry, model the business process and prepare an IDM. The second stage is called the "construct" stage. In this moment MVDs and specifications are developed and implemented. In the final stage, guidelines are prepared for deployment and early adopters' experiences are used to refine the BIM standard (Sacks *et al.* 2010).

1.3. Interoperability for concrete structures.

The exchange of information between architectural projects and structural projects still lacks adequate support, as well as the automation of structural analysis and exchange between diverse software applications in an open environment (Qin *et al.* 2011). One special requirement for interoperability for concrete structures, are the reinforcement bars. A lack of development in this area is commonly described. IFC is not perfectly prepared to receive this kind of information, and some software does not export this information as well (Kim *et al.* 2013).

To provide efficient interoperability of reinforcement bars, some authors suggest that these elements should be shared as individual elements within assembly, considering their relationships to the parts in which the bars are inserted. It is also important that systems consider the differences in the reinforcement bars of cast-in-place and precast concrete structures, since both have different needs (Aram *et al.* 2013). Also, semantic web can be used to promote interoperability between BIM models and product catalogues, such as precast concrete structures (Costa, Madrazo 2015). However, cast-in-place concrete structures don't follow pre-determined shapes or catalogued elements, and have other special requirements for interoperability.

When considering shapes for modelled objects, literature presents three possibilities: (i) objects can be disjoint (meaning that they never occupy the same space), (ii) nested (meaning that one shape is completely inside the other) and (iii) overlapping (when one shape is only partially occupying the same space as the other). These concepts are extremely important for cast-in-place concrete structures, because structure elements often are overlapping (such as the place where beams meet columns) or nested (such as reinforcement bars inside any given structural element). It is important for software to

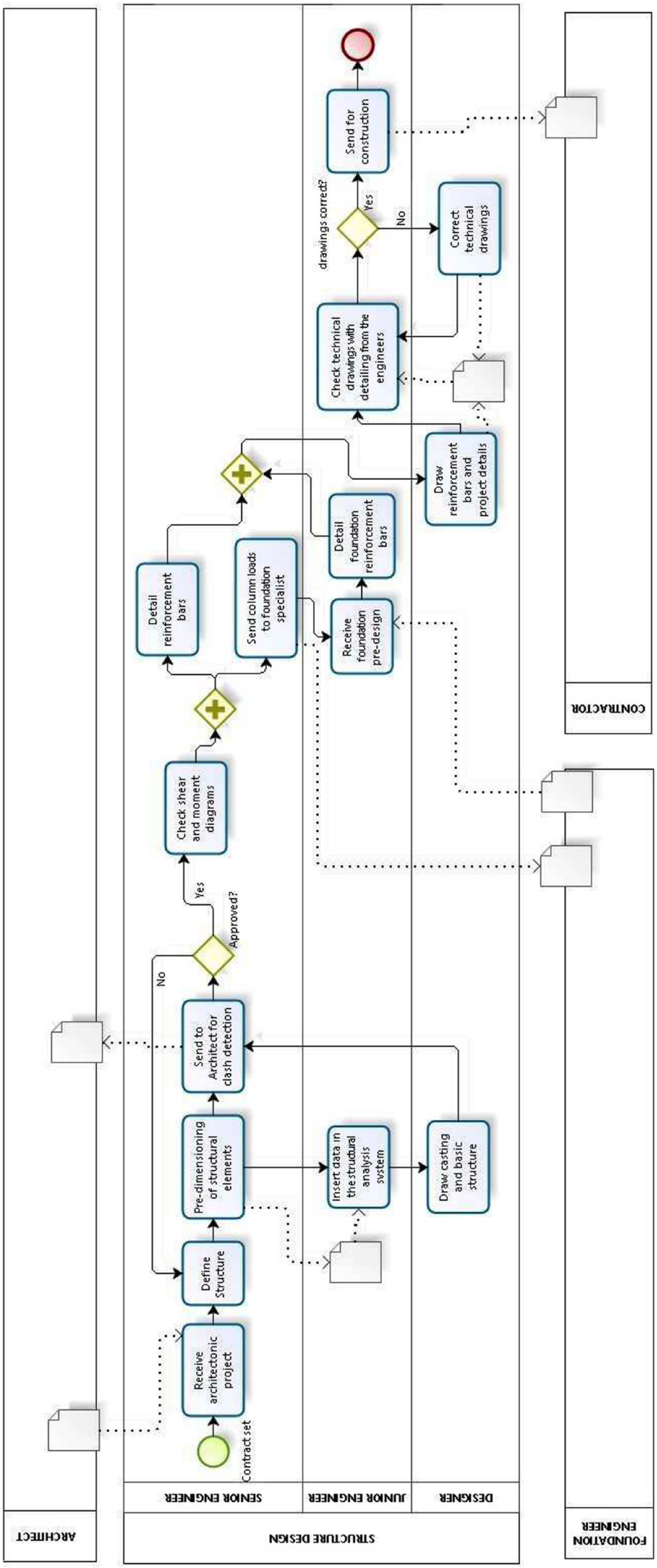

Fig. 4. Process map of a structural design company

subtract the intersecting areas, in order not to generate errors in the concrete quantity take-offs (Venugopal *et al.* 2012).

1.4. Process maps

Based on literature and in industrial best practices (Grilo, Jardim-Goncalves 2010; Kim *et al.* 2013; Muller *et al.* 2015), a process map using BPMN to detail the information flow and tasks in a structural engineering design company was carried out. Firstly, a company that doesn't use BIM was considered. As show in Figure 4, the process without BIM, requires many stages of clash checking, verification and file transferring. These files transferring's are often not in the same format, so users need to export files to different formats and sometimes even re-enter data in different systems.

Based on further literature (Aram *et al.* 2013; Sacks *et al.* 2010; Venugopal *et al.* 2012), it was possible to suggest a process map with the use of BIM, shown in Figure 5. This represents an improvement on the process, since many tasks and file transfers could be simplified or even excluded, minimizing errors and saving time. In this map, BIM is shown as a repository to aggregate all the information needed.

With the use of a BIM model as a repository, these processes become much more automatized, and designers may insert their data directly in the model repository, minimizing or automating clash and error detection. For this process to work, all users involved must either work on the same platform or use an interoperable open file such as IFC. From the process maps, it can be noticed in the importance of data interoperability, since for the use of a BIM repository, users should agree on an interoperable format. Hence, the experiments with data interoperability were developed. The present paper presents interoperability tests of IFC for cast-in-place concrete structures, and some suggestions for improvement of this standard, in an attempt to facilitate this process, allowing users to communicate and interoperate properly.

1.5. Interoperability experiments for IFC

Generally two non-visual methods can be used when analysing IFC models: direct text or direct objects. As the text may vary, the best method is the comparison of objects. The procedure for certification of Building Smart uses a combination of visual and syntactic tests. At first, models originated in an application are exported and imported within the same system and then exported to other software. The certification process is based on real life needs of IFC interoperability. It can be done by exporting simple objects, such as a wall, a wall with an opening, or by testing complete and more complex models, such as a commercial building. Tests with complex models allow evaluators to assess the interoperability in situations that are closer to the reality (Jeong *et al.* 2009).

Three main kinds of interoperability export/import tests are described: one-to-many, one-to-self and many-to-many. In one-to-many tests, one model generated in one system is exported to many other systems. In many-to-many tests, models from lots of different software are exported to other systems and in one-to-self experiments, one model is exported and imported in the same application (Lipman *et al.* 2011).

When discussing interoperability assessment, it should be taken into consideration what kind of BIM objects are being analysed. Such objects can be divided into three main categories (Eastman *et al.* 2008):

- *Made to be stored*, such as plumbing and electrical parts, are modelled only once according to the catalogue.
- *Custom made*, such as windows and doors, are also catalogued, but need to have parameters that the user may change.
- *Designed-engineered components,* more complex, need to be designed, detailed and manufactured according to customers' requests, so the BIM components need to be developed for each situation and specific software for these purposes can be used.

Since literature, along with the development of the process maps, showed some fragility in BIM data transferences, this research focused primarily in the data aspects of BIM interoperability, mainly IFC. This is because the lacks of correct standards lead to breaks in the information and process flows. Based on these import/export experiments described in this section, and especially considering cast-in-place concrete structures singularities as a Designed-Engineered component, experiments to evaluate IFC interoperability were developed. These experiments are better described in the next section, as well as its results and suggestions for improvement based on them.

2. Data analysis experiment methodology

The method used in this study is founded in a data analysis experiment, through file import/export from proprietary formats to IFC. The experiments were conducted twice, with a gap of five years to better analyse the development and drawbacks of data interoperability. This study focuses on cast-in-place concrete structures, which are designed components and present the biggest challenge for BIM modelling.

The experiment was based on experiments presented in Jeong *et al.* (2009) with precast concrete structures. Even though experiments are similar, the object of analysis presents some great differences, mainly due to the fact that precast concrete structures are subdivided in individual pieces, while cast-in-place concrete structures are monolithic, creating some special needs and barriers for interoperability as stated before.

Then, a similar procedure was developed in the experiments. Files containing structural elements were exported and imported among platforms, as shown in Figure 6. Not only the BIM applications were used, but also the IFC model viewer was employed. This allowed

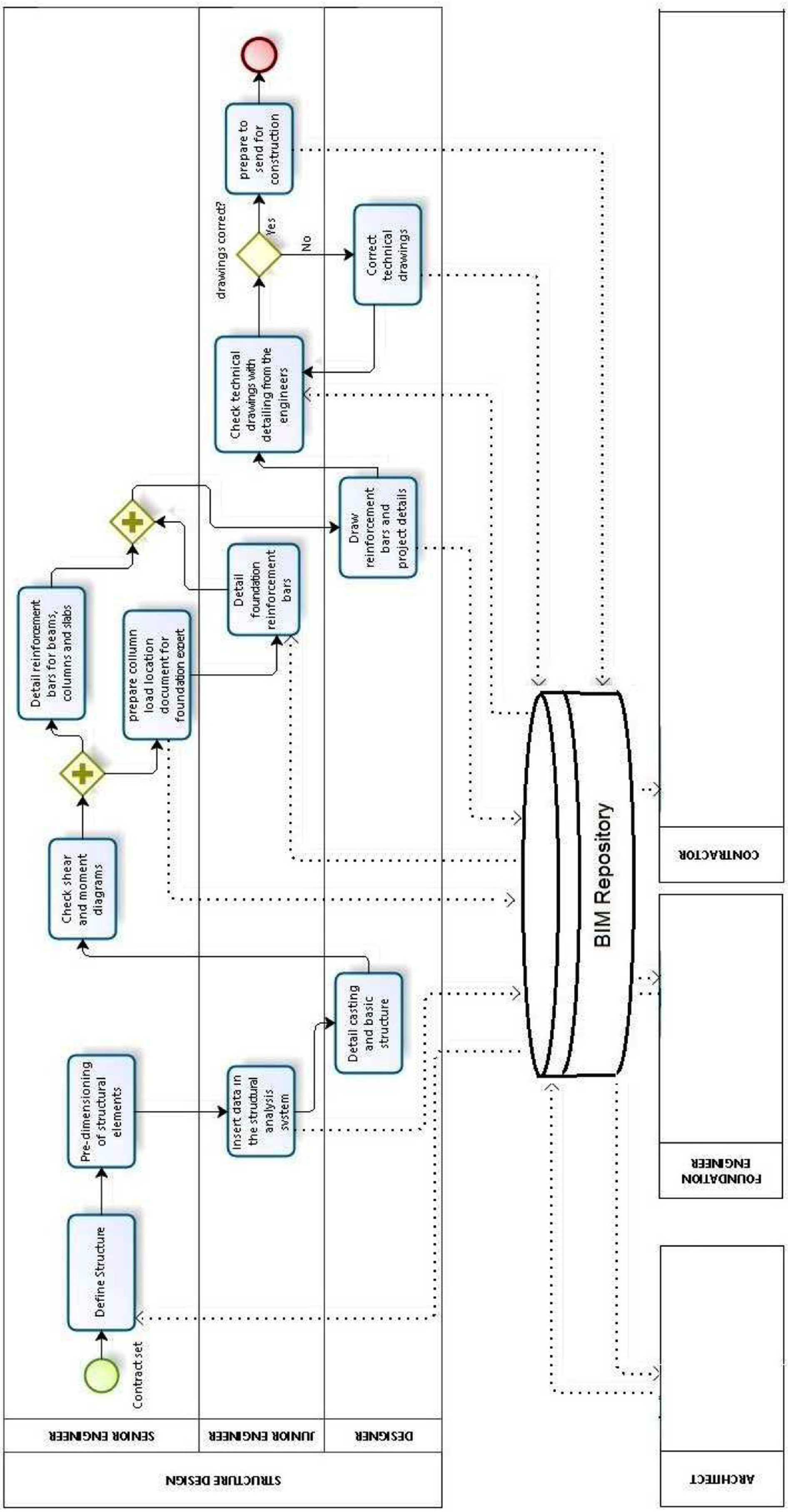

Fig. 5. Process map of a structural design company using BIM

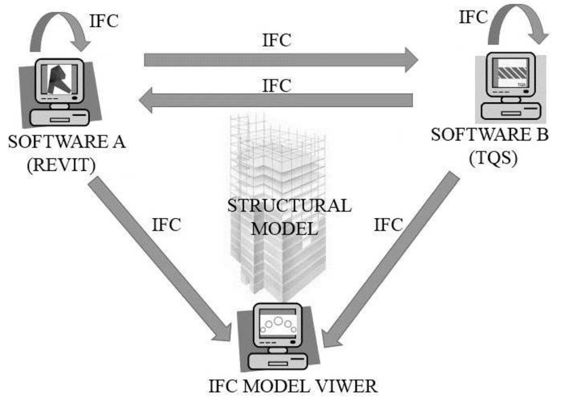

Fig. 6. Model transfers

researchers to verify if the software were having difficulties reading the model or exporting it. This kind of test is called many-to-many (including one-to-self roundtrips) (Lipman *et al.* 2011).

Data collecting was performed visually, by checking the model and marking on a spreadsheet which structural elements and their characteristics had been transferred correctly. The structural elements analysed in these experiments were: beams, slabs, columns, stairs and ramps (stairs and ramps were included in the category slabs). The characteristics checked in the models were based on the literature as well. Considering the special needs for cast-in-place concrete structures, the items selected to be analysed in this experiment were:

- Material/type, considering whether the material for the concrete characteristics were transferred correctly, and if the element was seen as the object as which it was proposed (pillar, beam etc.);
- Placement of the objects;
- GUID (Globally Unique Identifier) which is the code that identifies the objects;
- Geometry.

The transfers were marked as complete, incomplete and partial. Scores in a system similar to the Likert scale were attributed: 1 to complete, 0.5 to partial and 0 for incomplete. Then an average was calculated involving all the characteristics of each element. Authors in other studies (Jeong *et al.* 2009) had used only binary association in tests, and often needed to justify why an item was considered correctly transferred or not, so the need for a partial option during checking was perceived. Many objects were modelled, this included a complete building and sets of different kinds of elements:

- Beams: single span, multiple span, containing an opening, curved, with height variation and sloped.
- Slabs: simple monolithic, with an opening, ribbed, curved, sloped (ramp) and stairs.
- Columns: rectangular (one and two story-height), round, with section variation and L-shaped.
- Building: two apartments by floor, three story height with parking spaces below the building.

Some of the examples of the models produced in software A and B can be seen in Figure 7. After five years from the first tests, the experiments were conducted again using more recent versions of the software. The tests had the same structure as the first ones, using the same structure types and the same software.

3. Results from the data interoperability experiment

When transferring IFC models, some systems work as a sort of black box. They can generate IFC files, but are unable to receive IFC files. This was a great problem perceived in the first experiment. Software B could not receive IFC files, so a big part of the transactions was incomplete, as seen in Figure 8. This causes users to need to import reference files through 2D systems. Challenges presented by cast-in-place concrete structural models go beyond the fact that the structure is monolithic (for example, there is no physical separation between slab and beam), there is also the need for intricate reinforcing bars detailing, the use of specific concrete type, etc.

In the geometry analysis, the most difficulties met were related to sectioning the objects. Even though cst-in-place concrete structures are monolithic, BIM systems present difficulties treating it as such. A slab does not end when it meets a beam, and neither does the beam end when it meets the slab, so the volume in this intersection belongs to the slab as well as to the beam. This creates another problem, because when elements get sectioned, they are assigned with different GUIDs (Globally Unique Identifier) as well. The errors perceived the transferences of the GUIDs were mainly due to geometry errors. Systems have presented some difficulties with more complex geometries such as curves as well. Often curved elements were broken in smaller pieces, as shown in Figure 9.

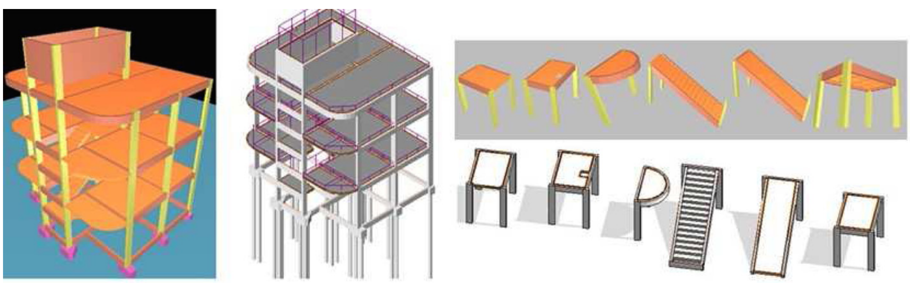

Fig. 7. Examples of models generated in Software A and Software B

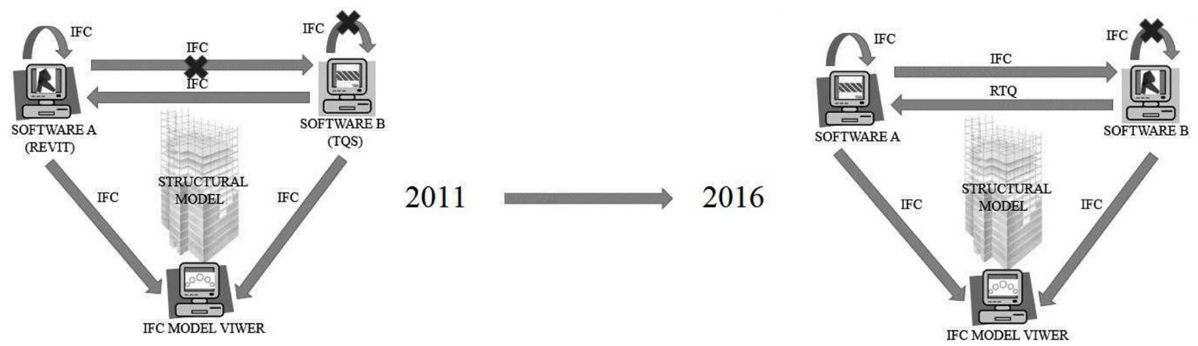

Fig. 8. Model transfers in the experiments: on the right, the first experiments transfers are show; on the left, model transfers from the second experiment can be seen (the transfers not executed are marked with an X)

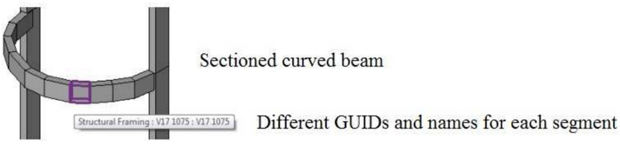

Fig. 9. Curved beam split into smaller parts

Another big concern was the reinforcing bars and detailing. Detailing is an important part of concrete structures, and hardly any information was transferred in the IFC files properly. Only in one case the reinforcing bars were transferred, and still as a characteristic of the object, not as a bar itself. No loads were transferred in any cases either. The need for better transferring of concrete structures models was also confirmed by literature (Aram *et al.* 2013).

Table 1 shows the averages described in the methodology section. The results show us that the biggest problem lies with the material characteristics, as it has the lowest of the average scores. 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 presented in writing.

In the second stage of the experiment conducted 5 years later, few changes and improvements were noticed, and in some cases, even some drawbacks could be perceived. This highlights the need for improvement in data interoperability for BIM. Even though software B is still not able to import IFC files, developers presented a plugin for Software A. This way, system A exports its files directly to proprietary files used by software B (called RTQ). A total of five transfers were analysed as shown in Figure 8. The same scoring methodology was used as in the original experiment. As in the first experiment, four characteristics were analysed through visual inspection: GUID, placement, geometry and material.

The averages from the second analysis can be seen in Table 2, and it could be perceived that materials are still the area that needs the most development in cast-in-place concrete structures, since they still have the lowest score. The new version of the software also had particularly a great difficulty in processing objects with openings and curved geometry. This time, some loads were transferred to the slabs; however in some cases the files joined permanent and variable loads. This can become a problem, because different types of loads use different coefficients and go through different combinations to de-

Table 1. Results from the first experiments

OBJECT	GUID	PLACEMENT	GEOMETRY	MATERIAL	TOTAL
COLUMNS	0.583	0.667	0.500	0.383	0.537
BEAMS	0.618	0.667	0.513	0.538	0.583
SLABS	0.583	0.633	0.578	0.525	0.580
TOTALS	0.595	0.656	0.530	0.482	0.567

Table 2. Results from the second experiments (2016)

OBJECT	GUID	PLACEMENT	GEOMETRY	MATERIAL	TOTAL
COLUMNS	0.780	0.800	0.740	0.800	0.780
BEAMS	0.767	0.967	0.767	0.733	0.809
SLABS	0.800	0.933	0.733	0.583	0.762
TOTALS	0.782	0.900	0.747	0.705	0.784

termine the final moments, sheer forces and compression on the columns.

Considering the average total score of the evaluations, it can be perceive that in the five year gap, there was an improvement of approximately 38% (considering an average of 0.567 for the first analysis and of 0.784 for the second).

A common problem found during transfers was related to the geometry of some structural elements as curves, sloped beams and beams with multiple spans. These structural objects were sectioned in multiple elements, losing their original structure and therefore creating new GUID codes. The model should consider the elements overlapping, since not only this is more geometrically accurate to reality, but also probably would prevent the program from creating a new GUID for each section of the structural element.

A suggestion to overcome the problems with loads and reinforcement bars is for both to be considered objects in IFC schema. These objects should be hosted in the structural elements, so this would make it easier for the systems to generate elements and to transfer them correctly. Another possibility to improve interoperability is for systems to give users the option to use the regulations of their own regions. This would allow a much greater integration with systems from different countries.

In addition, material wise, the tests didn't present satisfactory results as well. It is very important for material information to be transferred correctly, since the kind of concrete used relates directly to structural resistance. Loads should also be an object of attention, since loads presented great problems in the transfers. These two areas are especially relevant, since errors in these characteristics can lead to structural accidents, even endangering human lives. This aligns to views on the use of BIM for structural design by Jeong *et al.* (2009). According to the authors, the correct transference of material and loads are essential to efficient modelling.

Conclusions

Building information modelling is forecasted to be an important agent on interoperability in the AEC industry according to literature (Skibniewski, Zavadskas 2013). However, in order to develop and improve IFC data interoperability, the special needs of the AEC industry should not be disregarded in the development of the software and their ability to export proprietary files to IFC files. Special attention needs to be given to geometrical characteristics of the models, materials and detailing in order to develop interoperability through IFC in cast-in-place concrete structures.

However, in a gap of 5 years, some evolution in extensibility and adaptability were observed in all four elements analysed. The rise in 38% interoperability score shows some improvement in the field. This advance in the data concern in essential for improvement in business, process and services concerns, since professionals are not likely to advance with BIM to higher value levels without technical developments in the more basic levels, especially concerning data. This is due to the fact that when data is not transferred correctly, not much can be developed in the structural analysis and modelling field. So, cast-in-place concrete's unique characteristics should be considered in future versions of IFC, especially the overlapping of structural parts, the use of reinforcement bars and the need for precision in loads and materials.

It could also be noticed that the use of BIM would represent an improvement on the structural design process. The process can become much shorter, and files exchanges are minimized, especially considering BIM as a repository. Also the communication with other companies can be greatly improved, since a BIM repository may connect structural engineers, architects, foundation engineers and contractors. Since literature and the development of the process maps showed some fragility in BIM data interoperability, this research focused primarily in the data aspects of BIM interoperability. The other three concerns (Service, Process and Business) should be addressed with more depth in the future in further research.

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