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CURRENT STATE OF DATA EXCHANGE BETWEEN ARCHITECTURAL AND STRUCTURAL ANALYSIS MODELS - A CRITICAL REVIEW

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Abstract: Open format data exchange is currently the most applicable and promising way of exchanging building data between architectural and structural analysis BIM models. Industry foundation classes (IFC) building data model is the only open and neutral data format supported by all leading software products for these two disciplines in the construction industry. However, numerous interoperability issues will have to be overcome before seamless data exchange is achieved. buildingSMART International as the organisation responsible for the development of this data model is at the forefront of developing standards related to the data exchange and to the schema itself. Additionally, the organisation certifies software solutions that support the export and/or import of data with IFC schema. All these parameters are closely analysed as actors and processes that influence the data exchange. The case study on which this research is based, demonstrates how interoperability problems occur regularly across all the certified software tools. In order to pinpoint the origin of these data exchange problems, they are located within the described interoperability parameters. In that way all difficulties arising in the process of implementing open exchange format before reaching the end user are documented.

Keywords: Data exchange, industry foundation classes, architectural BIM, structural BIM.

1 INTRODUCTION

The popularity of Building Information Modelling (BIM) is increasing across all disciplines that take part in the planning process. New disciplines continuously join the process. BIM workflow on the second stage, called BIM Level 2, is achieved with a model-based collaboration. BIM Level 3 workflow manifests through the use of a network-based model (Succar 2009). In order to reach the second stage and facilitate collaboration, seamless data exchange between the disciplines must be achieved, which is also the ultimate goal of software interoperability and buildingSMART (buildingSMART 2017).

Collaboration based on BIM can be achieved in two different ways: with open BIM and closed BIM. The open BIM approach achieves interoperability through a non-proprietary format whereas closed BIM uses proprietary formats. European statistics of AEC (Mirza & Nacey Research Ltd 2015) show that offices mostly perform tasks of a single discipline, and therefore usually choose a software solution for their own needs without consideration of future collaborations. The next stage of BIM workflow needs to facilitate work with an integrated model. There is no single software solution that supports all the involved planning disciplines (Eastman et al. 2008). For those reasons the software interoperability

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has to be achieved through open BIM. Other ways of achieving the exchange are regarded as special cases and do not represent current or future general practice.

Industry Foundation Classes (IFC) based exchange is a standard for BIM based data exchange with over 150 software solutions claiming to support the schema (buildingSMART 2017). Leading market software applications in the fields of architecture (21) and structural analysis (32) support either import or export or both of IFC data models.

The research presented in this paper addresses the specific data exchange issues regarding the interdisciplinary collaboration of architectural and structural engineering. While the current state of technology is assessed, the weak spots are highlighted based on the preceding research (Šibenik 2016).

Thereby real case scenario interoperability testing of the data exchange is used. Besides a significant progress in the development of open standards, software tools are still not able to provide a working and reliable exchange. The exchange between an architectural and structural analysis model is taking place from the early stages of the project, and it is needed after almost every change. There is very little research on this topic, especially with regards to its occurrence and benefits for structural engineers. This research aims to contribute by reviewing the key interoperability parameters and detecting problems that arise before IFC schema is implemented in software solutions.

The paper is divided into four parts, where the first part analyses three different parameters affecting the interoperability. Parameters are actors (organisation, software developers and users) and processes (standards and certification). It reviews the organisation responsible for the development of IFC standards as a first parameter, existing standards and their application as second and the software tools certification for the open exchange as the third. In the second part the methodology for testing will be introduced; in the third part the results will be presented; interoperability problems will be related to the described interoperability parameters and discussed in the fourth part.

2 KEY PARAMETERS IN DATA EXCHANGE

2.1 Actors: buildingSMART organisation

Industry foundation classes are developed by the International Alliance for Interoperability (IAI) which was formed in 1996, and since 2008 has been called buildingSMART International (bSI). The following description of organisation is a summary of the information provided on the website buildingSMART (2016).

The head of the organisation is the International Council, which consists of two representatives from each buildingSMART chapter. That is the legal governing body of bSI. Currently there are 18 chapters worldwide as territorial membership organisations which are concerned with local open BIM implementation. Members of bSI and its chapters can be governmental bodies, institutes, commercial and non-commercial entities. In bSI there are two membership types, chapter and organisational members. Two representatives from each chapter make chapter members in International Council. Organisational members pay a membership fee depending on whether they are strategic, international or standard members. According to the fees, organisational members can take part in different number of chapters and have one or two votes in the Standards Committee.

The board of directors is elected by the International Council. It is the body in charge of leading the organisation and providing governance oversight. Operational leadership is carried out by the Management Executive. It is currently transitioning to be constituted of employed professionals instead of volunteers.

The Strategic Advisory Council (SAC) consists of several leading multinational enterprises. It is involved in defining bSI strategy, priorities and focus. It is built of strategic members which are currently ARUP, Autodesk, HOK, Nemetschek, Trimble and Kajima.

The bSI has three core programs: user, standards and compliance, which are (or going to be in the future) put into practice by other organizations. The International User Group (IUG) supports industry professionals that work with bSI standards. It is made of chairs of chapter user groups, whereby UserCom is its executive committee.

The main program of the organisation is the standards program. The Standards Committee (SC) is a body overseeing the whole process and is comprised of chapter and organisational members' representatives. The SC appoints the Standards Committee Executive (SCE) made of 6 members, with user and technical representation, which is the body executing the standards program.

Rooms are open groups of people and organisations that have a common goal to improve a specific domain in construction and operation of the built environment. They are an open fora, but only chapter and organisational members have the right of vote. Each room has its Steering Committee that leads and liaises it with the SCE and is formed from member or chapter representatives. Currently there are five active rooms:

- Technical Room – introducing buildingSMART with fundamental technical advancements to be used with open BIM, supporting the development of an IFC model to fully meet users' needs and ambitions
- Building Process Room – tools, guidelines and manuals for workflows, processes and procedures, using open BIM in the construction industry
- Infrastructure Room –development of open data standards for infrastructure
- Product Room – development and provision of processes, templates, tools and functionality for use of open BIM, resulting in buildingSMART Data Dictionary
- Regulatory Room – standardisation and provisioning of tools, guidelines and manuals for open BIM for building regulators

The Standards Committee Technical Executive (SCTE) is appointed by the SC and comprises of two neutral leaders and two representatives from each of the rooms, with both technical and user representation. It coordinates standards and compliance programs, ensures consistent technical approach for rooms and projects and advises the SCE for decision making.

Groups are formed to address a specific issue or requirement. There are currently two types of groups, support groups and working groups. Every group is supported by at least one room. The main task of a support group is coordination, support or expert advising, and they are expected to be long term. Working groups introduce a solution to a problem or a specific project. Only chapter or organisational members can be part of groups. The existing ones are listed below:

Support Groups

- Implementation Support Group (ISG) – implementation and certification for buildingSMART standards
- Model Support Group (MSG) – creating and maintenance of buildingSMART IFC data model standards

- Dictionaries Technical Support Group (DTSG) – development of buildingSMART Data Dictionary (bSDD) standards and functionality
- Technical Advisory Group (TAG) – assisting and supporting the Technical Room, ensuring it is up to date to with latest academic developments

Working Groups

- bSDD Working Group – evaluation and testing of the bSDD features and functionality, promoting the utilisation with guidelines, practices and procedures
- BIM Guidelines Working Group – development of open access BIM guidelines and recommendations

The compliance program is currently led directly by the executive committee of bSI. Software certification is supported by the Implementation Support Group. Different types of certification are still in the early stages of development.

2.2 Processes: Standards

buildingSMART International Standards are the standards agreed on as "final" by the SC. In addition, there are other forms of standards relating to buildingSMART which are less relevant and are designed either on national levels or are still in development and are published as specification (SPEC). Some of bSI standards have been published by the International Standard Organisation (ISO).

buildingSMART specifies five basic methodology standards, some of which have been published as ISO standards, and some of them only as "bSI final" (buildingSMART 2016). ISO 12006-3 named "Building construction - Organisation of information about construction works - Part 3: Framework for object-oriented information" describes the taxonomy model, that is how the concepts are defined, grouped and their relationship, where basic entities of a model are objects, collections and relationships. It is also known as bSDD or International Framework for Dictionaries (IFD) Library. It specifies a language-independent information model, which can be used for the development of dictionaries for storing and providing information related to construction works (ISO 2007). ISO 16739 is called "Industry Foundation Classes (IFC) for data sharing in the construction and facility management" and specifies the exact conceptual schema and an exchange file format for BIM defined in the EXPRESS data specification language (ISO 2013). ISO 29481-1 (ISO 2016) and ISO 29481-2 (ISO 2012) are "Building information models - Information Delivery Manual (IDM)" standards where part one defines methodology and format and part two interaction framework. Both are concerned with the interoperability between software applications used during the planning process. Part one of the standard defines a basis for reliable information exchange and information sharing for users, as well as how user requirements are to be documented. Part two specifies, in which way events or "coordination acts" during the project have to be described. However, these two standards do not define how user requirements are to be implemented into a software solution. There is a proposal for the third part of ISO 29481 standard (ISO 2011) which is called Model View Definition. It stipulates a formal definition of how user requirements have to be mapped into a data model schema. These basic standards are represented in figure 1.

In addition, there are currently two MVD "bSI final" standards valid for IFC4 data schema which are "IFC4 Design Transfer View" and "IFC4 Reference View". The MVD Reference View is suitable for workflows, where a model is used only as a reference. The Design Transfer View is designed for workflows where the next task is performed with the same model and the modification of content is expected. mvdXML is the "specification of a standardized format to define and exchange Model View Definitions with Exchange Requirements and Validation Rules" (Chipman et al. 2016). It defines rules for mapping exchange requirements to the MVD. Additionally, the BIM Collaboration Format (BCF) application programming interface (API) and XML are standardized. The BCF is a format that allows workflow communication between different software applications to exchange messages through the use of a web interface. The bSI standard "IFC for Infrastructure" provides an IFC schema for infrastructure projects.

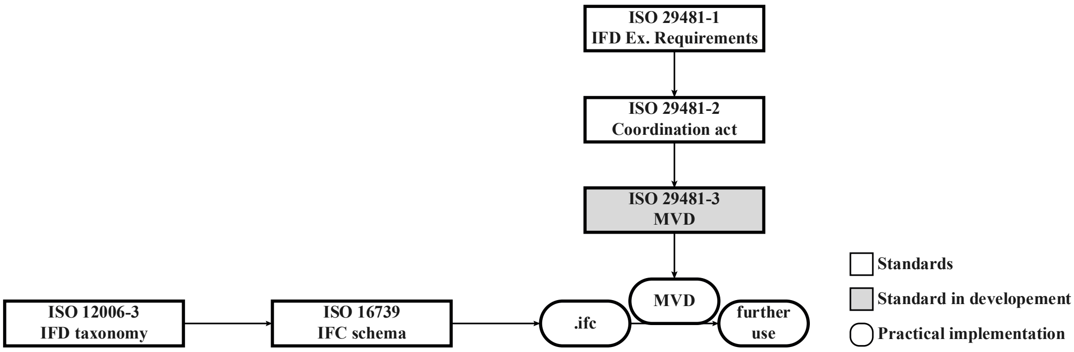

Figure 1 Relations of IFC associated ISO standards to their practical use

2.3 Processes: Certification

The certification process is currently only performed for the MVD Coordination View 2.0 (CV V2.0), which is created within IFC 2x3 schema. As the only certified IFC 2x3 subschema it is created for the use of exchanging building information between architectural, structural and building service BIM.

The certification workflow is described in Liebich et al. (2010) and for CV V2.0 it is organized by the Model Support Group and the Implementation Support Group. The workflow is divided into export and import certification. For the export certification, exchange requirement concepts are provided depending on the discipline for which the participating software is used. There are three different types: architectural, structural and building service. The export validation is carried out through a self-check performed by a software developer and an additional check by a certification tester. Consequently it is checked automatically and manually. The import certification involves importing a series of import calibration files that correspond to the exchange requirements. In addition, complex test files are provided. Then, manual self-tests are carried out and the results are validated by the certification tester. Finally, software developers design an adequate user interface for export and import as well as appropriate documentation.

For the latest version the IFC4 there are two standardized MVDs, the certification process of which is planned for January 2017.

3 METHODOLOGY

The impact of formerly described parameters that are influencing interdisciplinary data exchange are analysed using the conducted case study by Šibenik (2016). In the case study the occurring inconsistencies in data transfer from architectural into structural models were analysed, while focusing on the geometry issues in particular. Thereby an architectural model was created in various BIM software and transferred into structural analysis software using CV V2.0. A concept of interpreted data exchange units was used for the testing (Ramaji and Memari 2016), which defines the necessary interpretation of linear and planar building elements, connectivity and foundations. Using the concept, data inconsistencies or missing data after the transfer were identified.

The results of the preceding study showed that the correct import and interpretation of building elements depend on the combination of used software applications. In the next step, the identified inconsistent elements are compared with the concept list for CV V2.0 and the appropriate software checklists. The root concepts for CV V2.0 are a selection of attributes and relations that apply to this MVD, which can be spatial, building, building service or structural elements. The concept list, which is available online for each of the root concepts (buildingSMART 2017), is used for the certification process. Concepts are marked as mandatory, optional, not relevant or as excluded. Furthermore they are indicated as an export or import requirement. The export requirements can be a requirement of architecture, building services or structural software solutions. Additionally, checklists are available (buildingSMART 2016), which explain how the certified software supported the concepts during the certification. The scope of the interoperability issues is assessed through the analysis of single problems. Using these documents, the data transfer problems identified in the case study can be exactly allocated.

4 RESULTS

Only some of the analysed elements are described to give an insight into the results. Representation type "MappedRepresentation" and the shape representation "Body" are valid and mandatory export and import concepts for columns. However, one software solution imports only "SweptSolid" representation, whereby the cross section is neglected. In the certification checklist both representations are described as supported. The axis of the column is imported and placed, but sometimes in the wrong position. The geometry axis concept is marked as optional information for both export and import requirements.

Structural analysis software solutions do not support import of slabs with multiple layers, so they are imported as homogeneous elements. The load bearing properties of the slab are not mapped to the specific exported layer but through its property set to the whole slab. Even if the load bearing property is "False", the element is still imported into the structural analysis program. Property sets and materials are marked as mandatory for both export and import. Depending on the import software checklist, property set and material layer set are either a supported or not supported concept.

A roof is mapped as IFC slab or roof element. Flat roofs are imported if they are mapped as aggregate elements in only one software solution. Element decomposition is as a mandatory concept in the roof concept list both for export and import. Import of decomposition is mandatory for slabs as well. Element decomposition of slabs is not described in the checklists, and of roofs it is supported or not supported.

Walls mapped as IfcWallStandardCase with both "Axis" and "Body" representation identifier are not always interpreted as planar elements. One software solution exports walls with air as middle layer as IfcWall aggregate elements, which are not properly imported. The information about layers are neglected and they are imported as homogeneous elements, similar to slabs. Material layer usage is a mandatory concept for all export and import cases. Depending on the software solution checklists this concept is described as supported or unsupported.

Openings mapped with the representation "SweptSolid" are usually properly imported with the imported wall. "Brep" representation mapping in one software combination results with the interpretation of openings as linear elements. Both representation are supported in the concepts of windows. Windows are described as predominately architectural elements in the list of root concepts, but one of the import structural software tools has windows concepts included in the checklist.

The connectivity interpretation does not take place in any of the interoperating software combinations. In the IFC dictionary there are relationships which make mapping of these information possible, for example IfcRelConnectsElements or IfcRelConnects-PathElements. In the bSI concepts for CV V2.0, the connectivity information as export requirement are marked as excluded, not relevant or optional depending on the element, while as import requirement they are optional for most of the elements. Consequently, they are usually not tested for the architectural export or structural import, and therefore not implemented in the software solutions. For IfcWallStandardsCase a concept that defines its connection with other walls is mandatory.

5 Discussion

Sole topic of this research are the interoperability issues between architecture and structural engineering. Generally, the first source of problem can be traced back to the certification process. Certified software does not necessarily support the concepts that it is tested for. The concept list specifies different requirements for export and import testing. The discipline specific requirements are only specified for the export testing. Specific software functionalities are not taken into account when certification concepts are defined. Consequently, it cannot be expected that all the concepts are part of every software. This is possibly the reason why software is certified without supporting all of the mandatory marked concepts. Other problem is that the test cases are not covering all the valid concepts of the IFC files. Sometimes even the concepts described as supported in the software solution import checklist are not properly or not at all imported. Hence, software solution certification cannot be regarded to be a valid interoperability indicator.

Data exchange needs to be one of the priorities for the rooms and groups within the bSI. Compliance program is directly led by bSI executive committee, and no part of bSI concerned with the software implementation of IFC involves end users in the process. Data exchange with open format is still too unreliable to be used in the construction industry. List of concepts must result from the exchange requirements, defined by end users and software producers, in order to serve its purpose. One of the possible solutions would be if they resulted from appropriate IDMs. Certification process needs to be improved and include different properties of each software solution.

Certification process is currently available only for CV V2.0. However, in the near future, the certification process will be performed for two new MVDs, for which the experience with the currently implemented CV V2.0 can be utilized to avoid similar problems. Design Transfer View is the new IFC subschema that will be used for the data exchange between architectural and structural analysis models in the future.

6 Conclusion

There is a gap between the products of bSI and their implementation in practice, which is limiting the use of the open format IFC. The process that takes place between the IFC standard schema and its implementation by software developers must be reconsidered. Certification process is general and it is not completely suitable for any software solution. Technology problems must be resolved before BIM workflow on stage 2 can be achieved.

It is necessary for the users, software producers and bSI to cooperate in order to solve all interoperability issues.

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