

Design-to-design exchange of bridge models using IFC: A case study with Revit and Allplan

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ABSTRACT: This paper presents a case study of exchanging bridge models between two commercial modeling applications using the vendor-neutral format Industry Foundation Classes (IFC). Particular emphasis is put on investigating the modifiability of the received geometry, a major aspect of design-to-design exchange scenario. The case study is based on two BIM models of a bridge at two different design stages provided by professional engineering consultancies. The paper describes the current IFC configuration options in the analyzed BIM design tools and the related mapping mechanisms. Next, the executed case study is presented, including the preparation of the BIM models for exchange, configuration of the IFC interfaces and mappings, and recognized geometric modifiability cases of imported building elements. Due to lacking support, the IFC 4 Design Transfer View cannot be used, yet. However, in the Revit-to-Allplan design-to-design exchange scenario, the IFC 2x3 Coordination View 2.0 serves as a suitable fallback solution. On the other hand, the exchange in the opposite direction (Allplan-to-Revit) does not seem viable for now. In both cases, the coordination scenario using the coordination views IFC 2x3 CV 2.0 is realistic, resulting however in limited modifiability of the received geometry.

1 INTRODUCTION

1.1 *Transition period towards BIM*

The AEC industry is on its way towards adopting Building Information Modeling (BIM) thanks to the involved increase in efficiency and quality in project execution (Eastman et al., 2011). The traditional drawing-based approaches are being gradually replaced by modern procedures based on information models.

To avoid economic damage caused by a too rapid implementation of BIM at a national scale, a transition period is usually planned so that the necessary standards, guidelines, and contract templates can be established (Borrmann et al., 2016). The prominent example is the United Kingdom, which made the use of BIM mandatory starting from 2016 (Cabinet Office, 2011). Among other countries, where government-driven initiatives have been planned, Germany is in the process of the step-wise introduction of BIM methods in public infrastructure projects in response to the governmental BIM road map named “BIM-Stufenplan” set up by the Ministry of Transport (BMVI, 2015). According to the roadmap, BIM in planning and construction is supposed to be the standard method for all federal infrastructure projects by 2020. For data handover to the public client, only

standardized, vendor-neutral data formats are supposed to be applied.

1.2 *BIM4INFRA 2020*

BIM4INFRA (“BIM4INFRA2020” n.d.) is a project aimed at developing and supporting the implementation of Building Information Modeling in infrastructure projects in Germany.

As part of the BIM roadmap, a number infrastructural pilot projects are being executed across Germany. They are supposed to gradually introduce the necessary practical experience to the diverse road agencies, engineering consultancies, construction companies, and other parties. In one of the pilot projects (Highway A99, Bridge 27-1), the conceptual design for a bridge was developed and the corresponding BIM model was created using Revit (Autodesk). In the next project phase, the detailed design was prepared on the basis of the conceptual design using Allplan (a Nemetschek Company). This is a typical design-to-design exchange scenario which requires the modifiability of the exchanged geometry. To transport the model information between the two design applications, the vendor-neutral data format Industry Foundation Classes (IFC) was used.

In the context of the project, a detailed analysis of the implementation of the IFC standard in both Revit

and Allplan was performed, focusing on the modifiability of geometry after the exchange of professional BIM models. To this end, models were exchanged in both directions. Additionally, IFC configuration options of these BIM design applications and the related mapping mechanisms have been analyzed in detail. The insights gained are documented in this paper.

1.3 Structure of the paper

This paper is organized as follows. Section 2 provides background including the latest advances in IFC in the context of infrastructure projects, geometry, exchange scenarios, and Model View Definitions. Section 3 discusses the current state of the IFC configuration options of the analyzed BIM design tools and the related mapping mechanisms. Section 4 presents the executed case study, including the preparation of the BIM models, configuration of the IFC export and import functions and mappings, recognized geometric modifiability cases and the results. Finally, Section 5 discusses the presented results.

2 BACKGROUND

2.1 Industry Foundation Classes

Interoperability is the ability to exchange data between software applications, which eliminates the need to manually copy data already created by one application. In the construction industry, exchanging data is of paramount importance due to its high level of fragmentation. Data can be exchanged using Application Programming Interfaces, proprietary formats of software providers, or vendor-neutral formats (Eastman et al., 2011). The latter ones play the integral role in the construction industry because they allow to preserve fair competition on the software market and to prevent the market from vendor lock-in (Borrmann et al., 2018).

Maintained by buildingSMART, Industry Foundation Classes is the most prominent vendor-neutral, international standard for exchanging BIM data in the AEC industry. It is widely supported by BIM authoring and downstream tools. In a broader sense, IFC is a Product Data Model (often called “schema”) which provides general definitions of objects to address all building information throughout the whole building lifecycle. In this paper, the reader will come across a term “IFC file” which is a population of the IFC schema. An IFC file follows the patterns and constraints stipulated by the schema and contains the actual instances of the IFC classes. Generally, such models are called populated data models, however, if their content is construction-specific, they are named Building Information Models.

The existing versions of IFC do not yet fully support the modeling of infrastructure assets, such as roads, bridges and tunnels. The respective extension

is currently being developed in the frame of the buildingSMART Infrastructure Room (bSI, 2018a) and will result in the full support of these facilities, enabling the data exchange and open access in the context of planning, realization and maintenance of infrastructure facilities. However, a number of BIM use cases (e.g. visualization, coordination, quantity take-off) can already be well realized by means of the existing (and implemented) IFC versions 2x3 and 4.

2.2 Geometry

In Building Information Modeling, two different approaches can be distinguished in modeling volumetric bodies (so called Solid Modeling). The first one – Explicit Modeling, known as Boundary Representation, describes a body in terms of its bounding surfaces. The basic principle is that the bounding surfaces, called Faces, are described by Edges, and they, in turn, are depicted by Vertices. The whole system of relationships between them is denoted as the topology of the modeled body. An alternative approach to Solid Modeling – Implicit Modeling – is based on a sequence of construction steps to describe a resulting volume. The approach is also known as Procedural Method. The available construction operations include Constructive Solid Geometry (CSG) operations as well as sweeps and extrusions. CSG employs the predefined geometric primitives (such as cubes, cylinders and pyramids) and combines them using the Boolean operators (such as union, intersection, and difference). The output is a more complex body, which can be used in further construction steps. Another example is an extrusion which is defined by a planar profile extruded along a desired vector (Borrmann and Berkhan, 2018).

When it comes to data exchange, these two approaches result in fundamental differences. Boundary Representation is straightforward to process and visualize in the receiving software application. It is thus well suited for use cases such as visualization, coordination, and quantity take-off. Implicit models, in turn, require the receiving applications to precisely reproduce all the modeling steps, which may become challenging for more complex geometry. At the same time, implicit models much better support the modifiability of the geometry on the receiving side as all construction steps and their parameters are available. For example, a column can be represented by a circular profile which is extruded for a given distance (height). However, this approach makes the applications’ export and import interfaces far more complex to implement (Borrmann and Berkhan, 2018). Both approaches, explicit and implicit modeling, are supported by the IFC data exchange format.

2.3 Exchange scenarios

In the construction industry, it has been recognized that interoperability between authoring tools should support the use cases defined by practice-based workflows resulting in precisely specified exchange scenarios. They are particularly helpful as the exporting application knows what is required (and also what is not required) and the receiving application knows what to expect (Eastman et al., 2011). Accordingly, only a sub-part of the full IFC schema has to be implemented.

One of the most demanding exchange scenarios is “Design-to-Design”. It requires to transport the geometry in a way that allows its modifiability in the receiving application. In this respect, explicit representations which are based on representing the objects’ surface by means of triangles for example, are of limited use. Instead, the use of implicit geometry is required, including sweeps and Boolean operations.

On the contrary, the exchange scenarios “Reference” or “Coordination” are fully supported by explicit geometry, as the geometry of the model exchanged is not subject to modifications. This means that the geometric representation of entities should be explicit so that the receiver can analyze and extract the necessary information. The scenario can be applied for clash detection between two domain specific BIM models, or for performing quantity take-off.

2.4 Model View Definitions

In order to meet the requirements of different exchange scenarios, buildingSMART has developed the Model View Definitions (bSI, 2018b), which define the subset of the IFC schema required to be implemented by software vendors to support a given exchange scenario in terms of geometry and semantics. This significantly reduces the effort required for the software vendors and the users better understand what information they should exchange.

The IFC 4 Design Transfer View (DTV) refers to the “Design-to-Design” scenario, and IFC 4 Reference View (RV) is designed to meet the expectations of the “Coordination” exchange scenario. The previous version – IFC 2x3 – introduced the Coordination View 2.0 (CV 2.0), Structural Analysis View and Facility Management Handover View. For the time being, the IFC 2x3 Coordination View 2.0 remains the most widespread version. It is a default and certified version which is generally supported by other BIM authoring applications, including Allplan and Revit. Such a BIM model is not supposed to be re-editable by the receiving application. It includes the definition for spatial structure, building, and building service elements with shape representations, including both, parametric (implicit) shapes for a limited range of

standard building elements, and the ability to also include non-parametric (explicit) shape for all other elements (bSI, 2018b).

3 ANALYSIS OF IFC INTERFACES

Besides the concepts of exchanging building information models using IFC, there remains a matter of the actual implementation of the IFC interfaces in the target software applications and their proper configuration so that the receiver can reuse the imported file in case of the DTV for example. This section discusses the configuration of the IFC interfaces in the two BIM design applications: Revit and Allplan. Figure 2.1 shows an example of an exchanged bored pile between Revit and Allplan using the IFC 2x3 Coordination View 2.0 and assigning different IFC classes to the same building element. On the left side, it can be seen that the imported pile is modifiable by a dialog box (1) when its geometric representation in the IFC file is an extrusion (IfcExtrudedAreaSolid object) – behavior similar to the native elements in BIM design applications; (2) shows that the pile cannot be modified even though it has the same geometric representation as in case (1); (3) presents an imported pile which – in principle - can be modified using control points placed on all its surfaces (imported from the IFC file as IfcFacetedBrep object). However, this is an impractical option because the diameter cannot be easily changed if needed. In addition, (4) shows a heavily tessellated pile (IfcFacetedBrep object) which can be modified by a large number of control points, however not in a meaningful manner. This example shows that the configuration of the IFC export interfaces has an influence on the imported elements in the target BIM authoring tools.

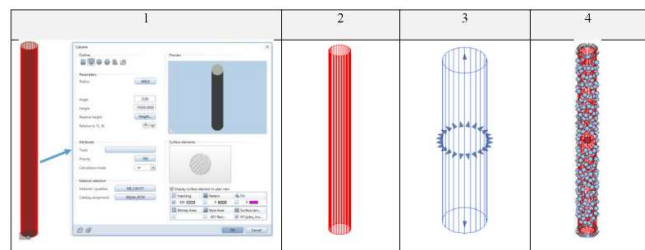


Figure 2.1 Different cases of geometric modifiability based on an imported bored pile.

3.1 IFC interfaces

BIM design applications support data exchange via IFC. This means that they provide import and export modules, which translate the internal proprietary models (geometry and semantics) into the IFC-compliant model and vice versa. An example of an IFC export configuration interface can be seen in Figure 3.1. The configuration interfaces offer to export project models using different MVDs. In addition, they

allow the user to choose certain project-specific options such as export only specific types of elements, support of free-form geometry, level of tessellation and others.

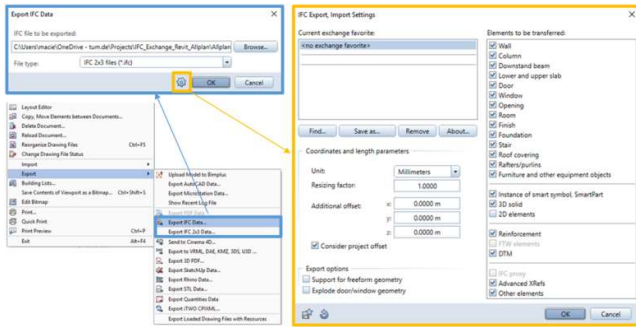


Figure 3.1 Allplan: example of an IFC interface.

3.2 Mappings

When a precise configuration of the IFC export is necessary, the options provided by the GUI are not sufficient for most real-world cases. The missing aspect relates to mappings of building elements and properties. Because of differences in data models of individual software products and the IFC schema, the users must specify how the building elements and properties must be translated into IFC-compliant objects. For the needs of the users, software vendors have developed template and mapping mechanisms to automate this process.

3.2.1 Building Elements

The receiver of an IFC file usually expects that all objects are of the correct IFC type – for example, a pile is of type IfcPile. An issue is the mapping of internal data types onto external IFC entities, as sometimes a 1:1 mapping does not exist. For example, IFC types might not exist in a BIM authoring tool or vice versa. In this case, the BIM authoring applications should provide the users with means for the configuration of how the proprietary classes of their data models are mapped to the respective IFC types. In case of building elements, a fallback solution is the use of IfcBuildingElementProxy – a generic type – which however can cause problems in the receiving applications as the object type is unknown and it is hard to find the correct internal type automatically.

In the analyzed BIM design applications, there are two levels of mappings related to how building elements are mapped to IFC classes. The first one – general, which maps internal types onto IFC classes (using a respective mapping file to which the user might have an access), and the other – specific, which maps only selected internal types or individual building components to desired IFC classes (usually using a software-specific attribute assigned to selected build-

ing elements). The settings in the specific level overwrite the ones in the general level. An example can be seen in Figure 3.2, where an element of internal type “cylinder” is mapped onto the IFC type “IfcPile” by means of assigning an “IFC Object type” attribute with the proper value.

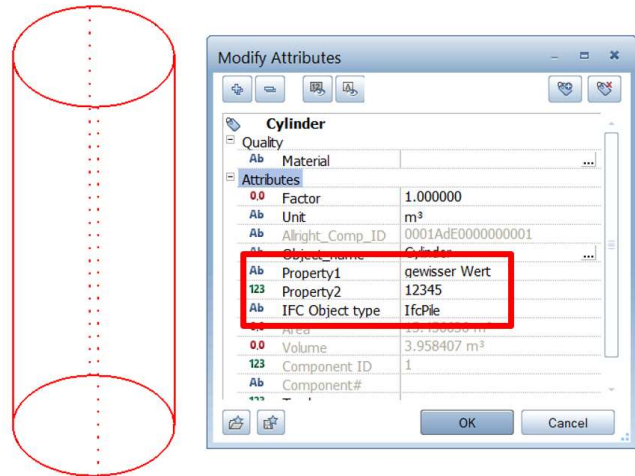


Figure 3.2 Allplan – example of a mapping of an internal Allplan type onto an IFC type.

3.2.2 Properties

It is often required by clients to provide respective properties assigned to building elements (such as compressive strength of concrete or exposure class). Besides the static attributes defined in the IFC schema (e.g. Globally Unique Identifier), user-defined properties can be created and added to an IFC project model. Properties must be grouped into Property Sets and then assigned to building components. Because of differences in data models of individual software products and the IFC schema, the Property Sets created in specific BIM authoring applications must be translated so that they comply with the rules stipulated by the IFC schema. Accordingly, the software vendors have developed mapping mechanisms to automate this process. An example of such mapping mechanism for properties can be seen in Figure 3.3. The mapped properties correspond to the ones shown in Figure 3.2.

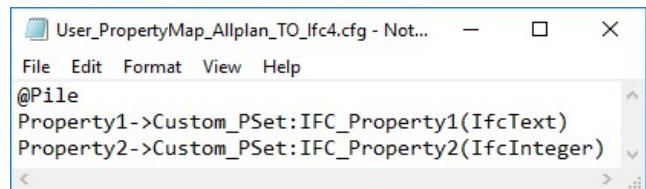


Figure 3.3 Property Set Configuration File for the custom properties in Allplan.

3.3 Geometric modifiability cases

This section discusses geometric modifiability cases, i.e. it specifies ways of how building elements imported from an IFC file can be geometrically modified in the respective BIM design applications (what

is their “behavior” when the user tries to geometrically modify the imported elements).

In the design-to-design exchange scenario, the desired manner is that all imported building elements can be geometrically modified in a similar way to how they are modified in the original BIM design application from which they have been exported. In a bridge model, for example, a bored pile should be imported as a cylinder whose length and diameter are directly modifiable. For wing walls, in turn, it should be possible to change the thickness and the position of the corner points. It should be possible to add openings/voids to these elements.

4 CASE STUDY: EXCHANGE OF BRIDGE MODELS

4.1 Model exchange

In this case study, two different BIM modes are exchanged. The first one, created as a conceptual design in Revit, is exported to an IFC file and then imported into Allplan. The other one, created as a detailed design in Allplan is exported to an IFC file and then imported into Revit as presented in Figure 4.1.

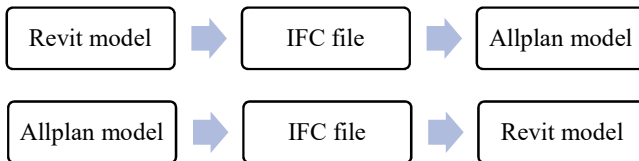


Figure 4.1 Two directions of the transfer of the BIM models in the executed case study.

4.2 Software versions

Since the actual implementation of the presented concepts in the BIM design applications is driving the outcome of this paper, their versions used in this paper are important. Table 4.1 presents the BIM design applications and their versions used in this paper. It must be understood, however, that after finishing this paper, some improvements have been released which could possibly change the outcome presented here.

Table 4.1 Software applications and their versions used in this paper.

Software	Version
Allplan (A Nemetschek Company)	2018-0-2
Solibri Model Viewer	9.8.17
Revit (Autodesk)	2018.2

4.3 Model Preparation

Because the analysis done in this paper is element-wise, the two project models need to be first preprocessed so that only selected building elements can be

exported to an IFC file and then imported into the other BIM design application. Accordingly, such types of building elements as: (1) beams, (2) abutments, and (3) piles are distinguished and the further analysis is based on the individual building elements of these types (for each type of a building element separately) and not on the whole project models as shown in Figure 4.2 and Figure 4.3.

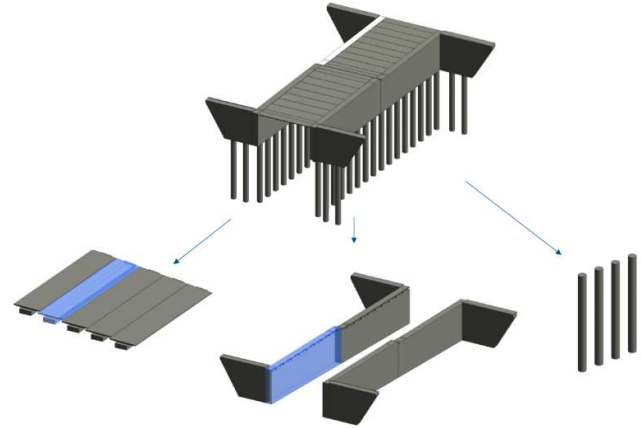


Figure 4.2 The Revit model is first preprocessed by distinguishing separate types of building elements.

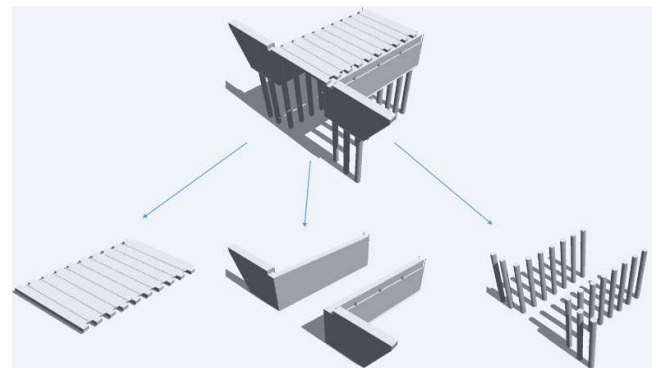


Figure 4.3 The Allplan model is preprocessed by distinguishing separate types of building elements.

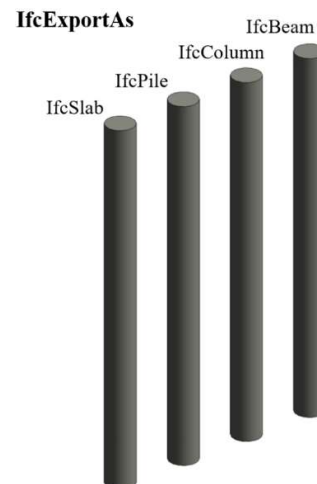


Figure 4.4 Revit: Different IFC classes assigned to individual instances.

4.4 IFC export configuration

4.4.1 Mapping of building elements

The preprocessed models consisting of the same building elements (as described in section 4.3) are assigned with different IFC classes by means of the mapping mechanisms described in section 3.2.1 and exemplarily shown in Figure 4.4.

4.4.2 Settings of IFC export interface

The building elements prepared as described in the previous section are exported many times using different options provided by the IFC export interfaces of the BIM design applications. It must be understood, however, that these options (besides the MVD) are exclusive to BIM authoring applications and differ among them.

In the Revit-IFC-Allplan transfer, the following options are considered: (1) Revit models are exported to an IFC file using the IFC 2x3 Coordination View 2.0; (2) Mixed “Solid Model” representation (turned on and off); (3) Low level of tessellation. In the Allplan-IFC-Revit transfer, the models are exported with the following options provided by Allplan’s IFC interface: (1) IFC 2x3 Coordination View 2.0; (2) IFC 2x3 data (a newer version of the Allplan IFC interface); (3) IFC 4.

4.5 IFC import configuration

In Revit, preliminary tests have been done in order to check if the mapping file which maps IFC classes to Revit categories while importing has any influence on the modifiability of imported building elements. Since the outcome of these tests is negative, the default Revit settings apply.

Because none of the IFC import options in Allplan refer to geometric representation of entities and the mappings between IFC classes and Allplan internal types are not explicitly accessible to the users, the default settings apply.

4.6 Intermediate checks

Before loading the IFC files into the BIM design application, all the exported building elements in these files are inspected using the Solibri Model Viewer in order to check their types of geometric representation.

4.7 Modifiability check in importing applications

The IFC files are loaded into the BIM design applications and the building elements are checked against their modifiability of geometry. The different modifiability cases can be seen in earlier presented Figure 2.1 and in Figure 4.5, Figure 4.6, Figure 4.7, Figure 4.8.

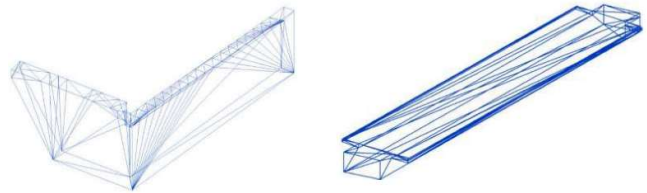


Figure 4.5 Revit: Imported wall and beam – unmodifiable.

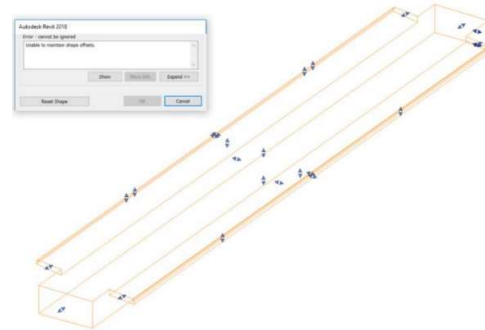


Figure 4.6 Revit: An imported beam – unmodifiable due to the inability to maintain its shape while any attempt of geometric modification.

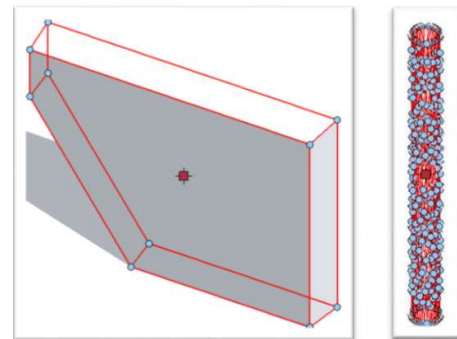


Figure 4.7 Allplan: Imported wing wall and a tessellated column modifiable by control points – the tessellated column represents the undesired case.

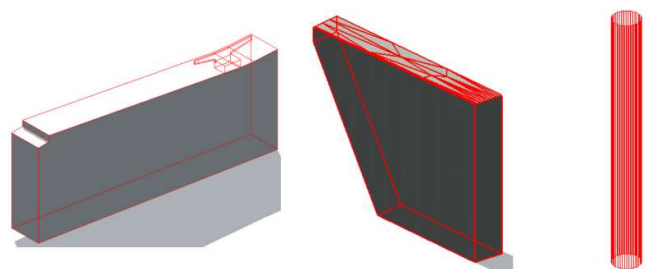


Figure 4.8 Imported unmodifiable elements (dump objects) – undesired cases.

4.8 Result Presentation

The outcome of the exchanges of building elements between Revit and Allplan using IFC can be seen in Table 4.2 and Table 4.3. More details regarding the geometric modeling of the building elements (reference to the second column in the tables) can be found in the Technical Report (Trzeciak and Borrmann, 2018).

Table 4.2 The outcome of the transfer of a BIM model from Revit to Allplan using IFC.

Revit			IFC File	Solibri	Allplan		
Building Element	Geometry internal type	IfcExportAs	Geometry Class	Geometry Type	Component Type	Modifiability Case	Geometry Remarks
Pile	Extrusion	IfcBuildingElementProxy	IfcExtrudedAreaSolid	Extrusion	Smart Symbol	Unmodifiable	-
		IfcSlab			Slab	By dialog box	-
		IfcPile			Smart Symbol	Unmodifiable	-
		IfcColumn			Column	By dialog box	-
		IfcBeam	IfcFacetedBrep	Brep	User-def. arch. Elem.	By control points	Triangulated
Abutment	"Free-form" element	IfcBuildingElementProxy	IfcFacetedBrep	Brep	Smart Symbol	Unmodifiable	Some faces triangulates
		IfcWall			User-def. arch. Elem.	By control points	
		IfcColumn					
Beam	Combination of extrusion and sweep	IfcBuildingElementProxy	IfcFacetedBrep	Brep	Smart Symbol	Unmodifiable	A face triangulated
		IfcBeam			User-def. arch. Elem.	By control points	
		IfcSlab			Smart Symbol	Unmodifiable	
		IfcColumn			User-def. arch. Elem.	By control points	
		IfcWall					

5 DISCUSSION

For the analyzed models, the desired design-to-design exchange using IFC4 Design Transfer View which allows geometric modifications of a model after its hand-over to another design application could not be tested. A number of reasons contribute to this. In the

Revit-to-Allplan exchange, the problem is that Allplan (version 2018-0-2) does not support the import of IFC4. In the Allplan-to-Revit exchange, Allplan does not offer to specify a model view definition during the IFC 4 export and the geometry of the entities is translated into explicit forms.

However, as a workaround, in the Revit-to-Allplan design-to-design exchange, the IFC 2x3 Coordination View 2.0 can be used, although CV 2.0 is not intended

Table 4.3 The outcome of the transfer of a BIM model from Allplan to Revit using IFC.

Allplan			IFC File	Solibri	Revit		
Building Element	Geometry internal type	IFC Object Type	Geometry Class	Geometry Type	Component Type	Modifiability Case	Geometry Remarks
Pile	Cylinder	IfcBuildingElementProxy	IfcFacetedBrep	Brep	Generic Models	By control points	-
		IfcSlab			Slab		-
		IfcPile			Structural Foundation		-
		IfcColumn			Not found	-	-
		IfcBeam			Structural Framing	By control points	Triangulated
Abutment	General 3D object	IfcBuildingElementProxy	IfcFacetedBrep	Brep	Generic Models	Unmodifiable	Triangulated
		IfcWall			Walls		
		IfcColumn			Not found	-	-
Beam	General 3D object	IfcBuildingElementProxy	IfcFacetedBrep	Brep	Generic Models	Unmodifiable	Triangulated
		IfcBeam			Structural Framing		
		IfcSlab			Floors/Generic Models		
		IfcColumn			Not found	-	-
		IfcWall			Walls	Unmodifiable	Triangulated

to support the design-to-design scenario. This exchange has shown that all the elements imported into Allplan could be made modifiable (via control points) by exporting them with a proper component type even though their geometric representation is Brep. This means that Allplan converts the imported Brep elements into internal objects which are geometrically modifiable by control points, which makes it possible to change the height, however not the diameter of the pile. The problem arises when the imported elements are (heavily) triangulated, which makes the geometric modifiability way harder.

The exchange in the opposite direction (Allplan-to-Revit) is possible using both IFC 4 or IFC 2x3 as Allplan supports exporting its model to both IFC 4 and 2x3 versions and Revit supports their import. However, the Model View Definition for the export using IFC 4 in Allplan is unknown. This exchange has shown that geometric modifications of imported elements in Revit seem to depend solely on the type of geometric representation of entities (and not on their component types as it is the case for imported elements in Allplan). The piles modeled in Allplan as cylinders have proved to be the only objects which could be modifiable by control points in Revit even though their geometric representations were Breps. The other elements could not be modified because either Revit did not provide this possibility (in case of tessellated elements) nor they were able to maintain their shape while any attempt of geometric modification (in case of non-tessellated beams).

The “coordination” exchange scenario (it was not the main subject of this case study though) using IFC 2x3 CV 2.0 seems to be fully viable between the analyzed software applications, as they both provide means for properly referencing building elements and accessing their properties.

BIM authoring tools are in constant development and the current state of their IFC interfaces presented in this paper can change in the near future. After finishing this paper, Allplan released a new version of the IFC4 import module, which could very likely change the outcomes presented here.

6 SUMMARY

This paper presents a case study of exchanging BIM models between Allplan and Revit, in particular emphasizing the limitations of the modifiability of geometry. The case study is based on two BIM models of a bridge at two different design stages provided by professional engineering consultancies.

For the time being, the IFC 4 Design Transfer View cannot be realized between these software applications. Instead, in the Revit-to-Allplan design-to-design exchange, the IFC 2x3 Coordination View 2.0 can serve as a fallback solution for now. The exchange in the opposite direction (Allplan-to-Revit)

does not seem viable for now. In both cases, the coordination exchange scenario using the mentioned IFC 2x3 CV 2.0 is realistic.

Since the BIM authoring applications are constantly upgraded, the results of the executed exchanges in this paper might very likely change in the near future. Another important aspect is the availability of the Bridge extension of IFC which is expected to be released in early 2019. It will provide additional entities and geometry representation tailored to the needs of bridge model exchanges.

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