Integrating Railway Subdomain-Specific Data Standards into a common IFC-based Data Model

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Abstract

Like in many other domains in the construction industry, concepts and methods of Building Information Modeling (BIM) are becoming more and more important for the design of civil infrastructure assets. Although several data formats have been developed to capture domain-specific data, none of these schemas can be used for holistic communication and cross-domain data exchange. In this paper, we present approaches for mapping existing domain-specific data formats in a more generic schema like the Industry Foundation Classes (IFC). This offers the possibility to develop coordination models for seamless data exchange and improved communication between project stakeholders.

1. Introduction

Over the last years, the use of Building Information Modeling (BIM) related techniques has been established in the architecture, engineering and construction industry (AEC). A large number of software products is already available that helps engineers to create and validate digital models of buildings. Two critical aspects in BIM are the representation of geometric shapes and semantic attributes within a single data container as well as the seamless collaboration among several domains.

Recent efforts have pushed forward the adoption of BIM methods also in the infrastructure sector. Particularly challenging, however, is the domain of railway design and operation (Bukhsh, Hartmann, & Stipanovic, 2016). Many disciplines are involved in the design process of a railway asset, e.g., alignment design, overhead electrification, railway equipment, noise barrier design and structural asset design like bridges and tunnels. The traditional paper-based working procedures have shown to be highly error-prone and inefficient as they do not provide appropriate means for handling the complexity involving a multitude of subdomains. BIM-methods can help to overcome these issues. However, for enabling an integrated design, data exchange is required across all these sub-domains.

In recent years, a couple of data formats were developed to store, and exchange data of specific sub-domains involved in a railway design process, but they are often limited to one specific use case. An example of such a format is the data model *PlanPro* developed by German Railways for representing information about railway equipment components such as signal systems or switch controls (Maschek, Klaus, Gerke, Uminski, & Girke, 2012). For pre-design decisions as well as for maintenance and operation purposes, it is often not necessary to store an exact geometric representation of the railway equipment components. Thus, this exchange format was designed to transfer detailed semantic information and satisfies the specific needs of railway equipment design in Germany. However, there are use cases such as geometric clash detections or visualizations, which require at least a core geometric representation of each component in the three-dimensional space.

From a BIM perspective, integrating and linking domain-limited data models is required to realize a higher quality of data exchange and reduce the error-prone and often manually re-

input of already generated data. This causes the need for domain-neutral and also vendor-neutral data formats such as the *Industry Foundation Classes* (IFC). This format is well-established for the exchange of building models. IFC can be used to merge data into a coordinated central model, which can then be used to perform data validation or clash detection between the components of federated submodels (Preidel & Borrmann, 2015).

In this paper, we show how domain-specific data formats can be translated into a more holistic and flexible IFC model. In detail, we compare the alignment description given in *PlanPro* with the available IFC classes to represent alignment axes an IFC model. Furthermore, we describe the opportunities how components can be placed in an IFC model. This paper also discusses the flexibility of IFC with respect to dynamic extensions by means of proxy objects and PropertySets without the need of an official schema extension for an individual domain.

The paper is structured as follows. Section 1.1 gives an overview of related work and related approaches. We will focus on the PlanPro data model as one specific data model to describe a possible mapping process of a domain-specific data schema to a more generic data framework. Two possible approaches converting alignment information and related element placement are presented in Section 2. Those approaches and their successful implementation show that it is possible to utilize well-established domain-specific data-formats in a BIM process and hence prepare the data for further analyses and simulations. We investigate some relevant classes of the input data and explain approaches to transfer them into the IFC schema. However, the proposed transformation from PlanPro to an IFC model is limited in some aspects. These issues are discussed in Section 3 and should be addressed in future research.

1.1 Related Work

In the last years, researchers and domain experts have developed a broad range of data models to carry information about civil infrastructure assets like roads and railways. These studies often put their focus on carrying semantic information and element descriptions.

Well-known data formats related to the field of railway infrastructure are *PlanPro* (Maschek et al., 2012) and RailML (Bosschaart, Quaglietta, Janssen, & Goverde, 2015). *PlanPro* was developed to exchange design data of train control systems, whereas RailML is more focused on operation issues of rail-bounded vehicles. Both of these formats are based on the Extensible Markup Language (XML), which is machine- as well as human-readable (Bray et al., 2006). For simplicity, these data models are called *Information Models* (IM) in the following sections. This term was introduced by Bukhsh, Hartmann, and Stipanovic (2016) and is used both for RailML and for PlanPro in this paper. Additionally to the development of the aforementioned formats, some initiatives investigated in ontologies and Linked-Data approaches (Turck et al., 2010). Wunsch et al. (2016) gave a comprehensive outlook on exchange requirements and possible data formats for these use cases.

Besides these separated approaches using IMs as exchange formats, Luteberget and Johansen (2018) took use of RailML to support and expand a CAD-based design application for railway safety equipment. They developed a plugin to check the compliance of their design data against national regulations at runtime. Their approach, however, is not applicable to perform cross-domain rules, which can require information for assets that cannot be modeled within RailML.

In contrast, the vendor-neutral data format Industry Foundation Classes (IFC) offers the opportunity to store detailed geometry as well as comprehensive semantic information. Initially

developed in the context of building models, IFC gets more and more extended to the needs of civil infrastructure assets. Some initiatives investigated on refining the geometric descriptions for large models, i.e., for exchanging tunnel or bridge models (Vilgertshofer, Jubierre, & Borrmann, 2016). Augele (2017) worked out the similarities and differences between RailML and IFC but did not take the recent IFC extensions for civil infrastructure assets into consideration. Amann et al. (2014) focused their research on the translation of alignment models given in several data formats and proposed a common meta-model. Their model became the base for the description in the IFC data schema extension describing alignments and was added to the official schema with the version 4.1 published in summer 2016.

The contributions of the abovementioned studies are of high importance because their concepts of structuring the relevant information in a specific sub-domain are derived from domain experts' knowledge. An international standard for exchanging digital models will never be capable of all regional, local or project-specific features and requirements. Nevertheless, additional approaches are required to realize cross-domain communication and data exchange between several project stakeholders since domain-specific formats are often only supported by a minimal number of specialized applications. Thus, connecting different Information Models into a vendor-neutral and domain-neutral data format like IFC can help to overcome this problem. IFC is common in the building sector; thus, there is already a broad range of model viewer and project management applications supporting IFC import and/or export. These programs can be used for project communication for building models as well as for civil infrastructure models. Besides that, converting data from IMs into IFC makes it possible to perform cross-domain simulations like geometric clash detections between components from different domains. However, since there is no specific schema extension for railway assets in the IFC schema yet, some problems occur during the mapping process, which will be discussed afterward.

1.2 Objectives & Challenges

As shown before, IMs provide a solid base of semantic information about a specific asset. However, it is not possible to use them for cross-domain communication and simulations. Therefore, another well-established concept from the building sector can be adapted: Federated models are used to coordinate domain-specific data during the complete lifecycle of a building. This approach is already standardized by the British Standard PAS1192-2 as well as by the ISO standard 19650. Preidel and Borrmann (2015) showed the necessity of working in federated domain models and merging them into a coordinated model.

Coordination and seamless data exchange are unavoidable between all project stakeholders to optimize planning processes in the construction industry. Non-coordination of issues and design data can lead to inconsistent data. Thus, a data structure should be chosen, which is capable of all these aims. Model-based data structures for buildings are often led by a three-dimensional geometric representation and a grid-based model orientation (axes and storeys in a building). Contrary to buildings, civil infrastructure models are often line-oriented. The representation of these alignment curves is typically split into a horizontal description in the xy-plane and its corresponding gradient described by a parametric coordinate s and the height z (Markic, Schlenger, & Bratoev, 2018). Besides that, there are many cases in a design process of a civil infrastructure asset, in which the engineer must deal with a large number of semantic values but can only provide a rough estimation of the product shape. Thus, a data format for railway coordination models should be chosen, which matches the following requirements:

- A line-oriented model orientation and product placements referencing relative to a given alignment.

- Three-dimensional geometric component representations in any granularity.
- The capacity to carry semantic information assigned to components.

IFC is capable of all these requirements. Therefore, we introduce mapping processes from pure IMs into the IFC format to remedy the disadvantages of pure IMs. Especially, the strong linkage between geometric and semantic information in an IFC model enables the user to formulate complex queries against the generated model. Cross-domain problems benefit a lot from the direct integration, e.g. by accessing semantic attributes of elements in a particular area or volume (Daum & Borrmann, 2014). Design decisions often require a detailed examination of a complex geometric situation, e.g., mounting several components of different domains on one pole. Hence, linking the requirements and design options of all sub-domains should be already investigated in early design phases.

We developed a software prototype to examine the possibilities and limitations of mapping an IM into an IFC model. In the case study conducted, PlanPro was selected as origin format. The prototype supports the alignment description and the placement of signals as point-based objects along a track. Although the validation of the proposed concept is based solely on PlanPro and provides only the mapping of alignment data and signals, the strategies discussed in the next sections can also be applied for other components like switches, axle counters, or platforms.

2. Approaches

As there is an increasing number of applications supporting IFC, several options exist to implement the proposed converter from IMs into IFC models. Currently, several IFC versions are in use. Thus, a short overview regarding IFC is provided.

2.1 Industry Foundation Classes (IFC)

The *Industry Foundation Classes* (IFC) are an open, vendor-neutral data format, which is intended to transfer information among different stakeholders across the lifecycle of a built facility. IFC is mainly focused on the building sector and has many classes to describe elements from different domains like architecture, structural analysis or HVAC. Although IFC is often related to data exchange in the planning and execution phase of a project, IFC models can also be used for operation and maintenance.

With version 4.1, the classes for describing alignments were added to the official schema. These classes offer the possibility to store information about three-dimensional axes, which are the base for line-based infrastructure assets e.g., roads, rails and their corresponding structures such as bridges, tunnels or platforms. Extension projects are currently conducted by *buildingSMART* to develop the necessary extensions of the IFC data model. This includes IfcBridge, IfcRoad, and IfcRail (BuildingSMART international, 2018). A small number of authoring tools already supports the import and export of *IfcAlignment* into or from an IFC file. However, the number of applications capable to interpret *IfcAlignment* entities is low compared to a massive range of tools supporting IFC for building models.

Although there is yet no standard defined for infrastructure assets in the IFC schema, many use cases in an infrastructure planning process are already supported by IFC. The IFC data model provides flexible extension mechanisms including proxy elements and user-defined property sets, which enable the user to perform analyses and simulations on these models and allow data exchange among different stakeholders. It is possible to use the generic *IfcBuildingElementProxy* class to model components without a specific definition in the data

schema. *IfcBuildingElementProxy* is derived from the abstract class *IfcProduct*. Therefore, it is capable of carrying a geometric representation as well as every other class derived from *IfcProduct*. Classes derived from *IfcProduct* can be placed inside the model using subclasses from the abstract class *IfcObjectPlacement*. A subclass of this class is the *IfcLinearPlacement* class, which places components (derived from *IfcProduct*) relatively to a given curve (BuildingSMART international, 2017).

Since IFC version 4.1, specialized classes are available to describe typical alignment curves used for civil infrastructure assets. The *IfcAlignment* class is derived from *IfcProduct* and *IfcCurve* and is used to place elements along the described curve. Figure 4 shows the relevant IFC classes used in the implementation approaches.

An international standard for exchanging digital models will never be capable of all regional, local or project-specific features and requirements. To mitigate this problem, IFC provides the concept of property sets. There are many predefined attributes (e.g., for walls, windows or beams). Additionally, it is possible to create user-defined property sets and append them to components. Thus, it is possible to extend the IFC data schema for individual requirements, while at the time the model remains interpretable by any software product that has implemented IFC reading capababilities.

In both presented approaches, an additional property set was assigned to every positioned component in the IFC model, which contains relevant attributes from the given PlanPro file. Every component in PlanPro has an individual identifier, which is stored as one property within the PlanPro property set.

2.2 Implementation strategies

Several initiatives already tried to convert existing object-oriented data structures from or into the IFC schema. Object-oriented schemas can be seen modeled as graph representations. Therefore, the main task is finding correlations between both graphs. For identifying links between IFC and CityGML entities Beetz & Borrmann (2018) made mainly use of spatial coincidences, whereas Stouffs, Tauscher, and Biljecki (2018) applied the triple graph grammar concept for these formats. The proposed mapping from IMs onto the IFC schema is rather similar to the latter approach. Both schemas have an object-oriented structure and vary in the purposes they were intended for. Thus, there is no 1:1 correlation between both graphs, but there are some classes, which can be correlated. Figure 4 at the end of this document shows possible links between both data schemas to map point-based products from PlanPro into IFC.

Figure 1 gives an overview of the investigated approaches to achieving the desired subdomain model integration. The first approach consists of pre-processing the original IM (PlanPro), then importing the resulting model into a BIM authoring tool and generating the IFC file by means of its built-in export facilities. In contrast to that, the second approach avoids applying a BIM authoring tool and instead makes use of an IFC programming library for creating a standalone conversion tool.
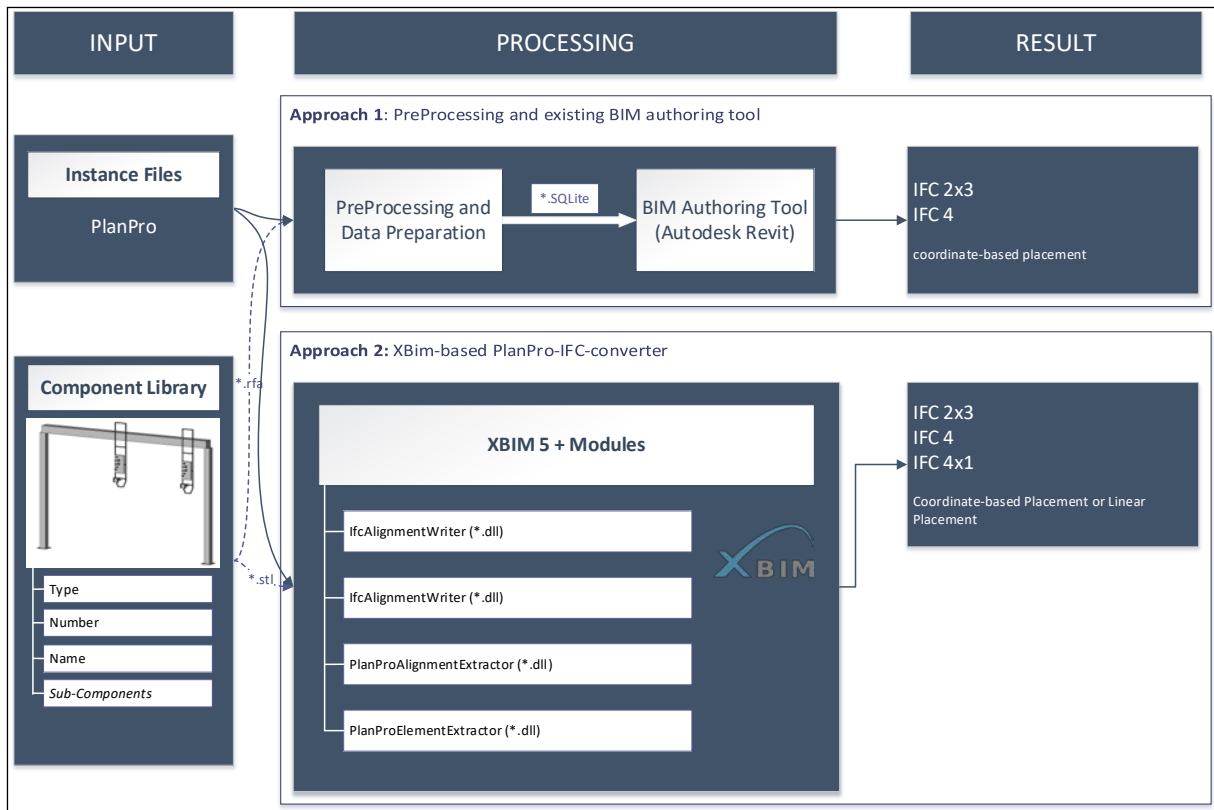
Figure 1: Different Implementation Approaches to convert Information Models into IFC Models. Approach 1 consists in pre-processing the original IM (PlanPro), then importing the resulting model into a BIM authoring tool and generating the IFC file. The second approach avoids applying a BIM authoring tool and instead makes use of an IFC programming library for creating a standalone conversion tool.

Existing BIM authoring tools offer much flexibility when creating new element groups and their respective geometry. Therefore, it is one option to use an existing application and extend it by a plugin that provides the required information in the modeling environment. For this case study, *Autodesk Revit* as a well-established BIM authoring application was selected. It has a powerful "family" editor to create new elements and can be extended using its Advanced Programming Interface (API).

A significant disadvantage of this approach is the overall dedication of BIM modeling tools for buildings and the limited support for linear infrastructure facilities. While applications like Revit organize their elements in grids and levels, civil infrastructure assets are mainly referenced to an alignment curve. Thus, Revit itself does not support the export of *IfcAlignment* Entities, but only positioning expressions in cartesian coordinate systems.

In the second approach, the framework *XBim* was selected to implement a stand-alone converter, which makes use of the IFC entities suitable to describe alignment curves. Additionally, the way of storing the placement of an individual component is addressed in detail. The next sub-sections provide an insight into the implementation process and limitations of the proposed concepts.

2.3 Product Catalogue

In the proposed concept, all available IMs are transformed into a 3D BIM representation to support coordination and informed decision making. Neither the components in *RailML* nor in PlanPro posses geometric descriptions in the form of *Boundary Representations (BRep)* or *Constructive Solid Geometry (CSG)*. For some components, however, PlanPro refers to

arrangement drawings. These drawings are independent of the manufacturer, and thus can be used for vendor-neutral tendering. Because of their generic character, a component library collects the geometric shape and parameterize these representations.

Every component has a certain drawing number and can have several types. All types have a slightly similar shape. Thus, it is possible to parameterize their geometric representation. Additionally, the arrangement drawings offer some additional semantic parameters like placement rules (e.g., the required distances to overhead electrification poles), which are covered by the library as well.

The generated family library establishes the base for both approaches. Due to restrictions on publishing and sharing these arrangement drawings, the component library is not big enough to cover all possible signal types. Hence, a cuboid is used as a geometric representation for a component if there is no reference to an arrangement drawing, or the arrangement drawing was not accessible.

2.4 Using *PlanPro* Data in a BIM Authoring Tool

Since Revit is not capable of any typical alignment format yet, a preprocessing tool was developed to prepare the required data of a PlanPro model for the use inside a Revit Project. Although Revit is not intended to be a modeler for railway equipment design, the family engine and the possibility to work with large property sets make it adequately generic and suitable for the proposed converter.

All coordinates of the alignment segments in a PlanPro file are described in a world coordinate system (DB Ref as a specialized system of the well-known Gauss-Krüger-System). Since Revit cannot handle large coordinate values, a preprocessing tool translates the given world coordinates into a local project coordinate system[1] (Markič, Donaubauer, & Borrmann, 2018). In a PlanPro instance model, the placement of components is given by the track it belongs to, the station kilometer and the lateral offset to the rail axis. Revit itself cannot process this kind of placement description; thus, the preprocessing tool calculates the (projected) cartesian coordinate. Thus, the BIM authoring tool itself is mainly used to place the right family inside into the modeling environment and sets the required semantic attributes. The preprocessing approach also offers the flexibility to use the prepared data in other tools.

After finishing the modeling process, the IFC export interface of Revit was used to create the desired IFC model. Although the export interface offers the possibility to adjust some preferences (Trzeciak & Borrmann, 2018), it cannot create IFC models using *IfcAlignment* and *IfcLinearPlacement* entities.

The resulting *IFC* model in the versions 2x3 and 4 can be displayed in all common IFC viewer applications.

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[1] It must be noted that this local coordinate system is still a projected one with the respective distortions that must be taken into account.
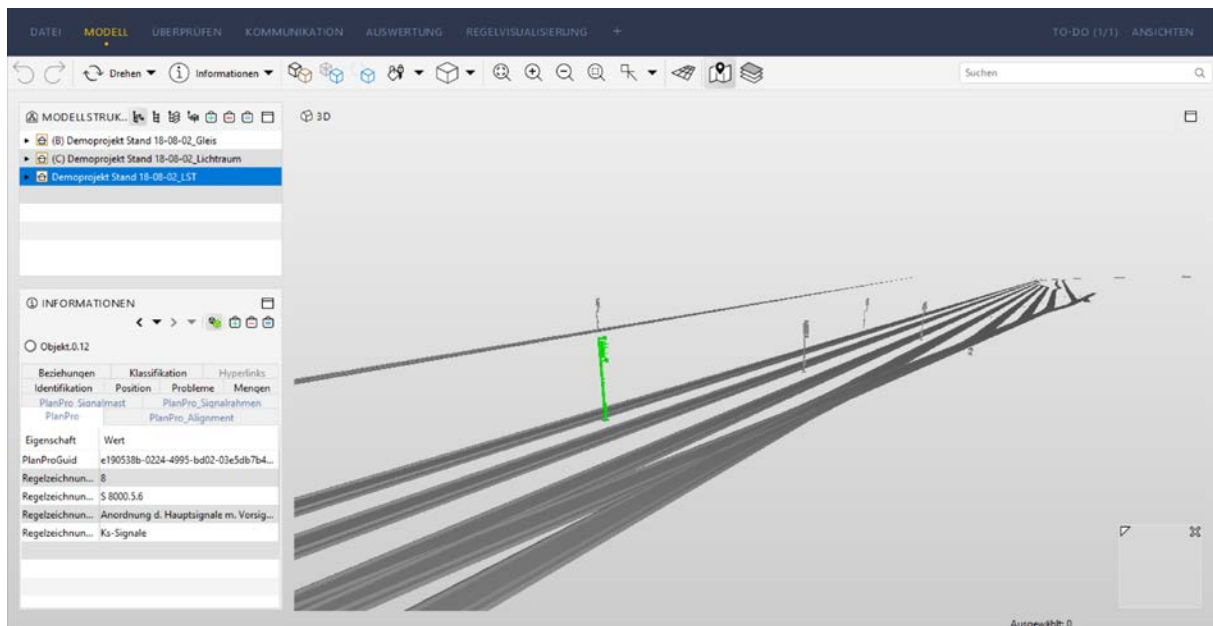
Figure 2: Resulting Revit-IFC Model in Solibri Model Checker

2.5 Using XBim Framework for a Refined IFC Model

As discussed above, the aim of mapping an existing IM into an IFC model can be solved with the first approach using existing modeling software. The resulting model contains signals with an individual geometric representation depending on the given arrangement drawings and semantic attributes. The alignment is modeled with a volumetric boundary representation as well. However, the plugin-approach leads to the loss of a direct relationship between the alignment curve and the implicit placement indication (station and axis reference) of all elements since cartesian coordinates now describe the position of any element.

The second approach remedies the disadvantage of using Cartesian Coordinates for every individual element placement. Instead, each element's position is described relative to an alignment curve in the resulting IFC model. Once the alignment curve in the xy-plane is modeled, it is possible to locate an element by a new coordinate system (s, z) in which s describes the stationing axis and z the height at a specific station s (Markic et al., 2018). With additional offset parameters in the longitudinal, lateral and vertical direction the exact component placement is defined.

To realize the second approach, we implement a direct mapping to IFC without using an existing BIM authoring tool in the toolchain anymore. Instead, the *XBim Toolkit* is employed to create the desired IFC model using *IfcAlignment* and the linear positioning concept along the alignment curve according to ISO 19148. *XBim* is an open-source framework for importing, editing and exporting IFC models and is licensed under the *CDDL Open Source License* ("xBIM Toolkit," 2019).

The required methods are split up in several modules to make the code as reusable as possible. This concept enables the developers to extend the implemented prototype for further requirements or other applications, which need similar methods. The modules *IfcAlignmentWriter* and *IfcElementWriter* are entirely decoupled from the libraries extracting data from a given PlanPro model. The modules *PlanProAlignmentExtractor* and *PlanProElementExtractor* extract the necessary data and insert suitable IFC entities into a given IFC model.

As shown in Figure 1, the created component library is used in both presented approaches. Since *Revit* families are stored in the proprietary **.rfa* format, the contained geometric and semantic data are not accessible from applications outside the Autodesk product family. Thus, an export of the geometry into the open geometry format "STereoLithography" (*STL)* was required. STL stores a given body as a triangulated boundary representation and is, therefore, an explicit geometry representation. It can easily be converted into an IFC geometry representation like *IfcTriangulatedFaceSet*.

Model View Definitions (*MVDs*) are used to define a subset of the complete IFC schema and add additional requirements such as geometric representation method or necessary attributes (Beetz, Borrmann, & Weise, 2018). The chosen IFC entities used in the standalone approach are based on the Reference View of IFC 4. Unfortunately, there is yet no official MVD for *IfcAlignment* and *IfcLinearPlacement* entities. However, the generated IFC models can be opened and visualized by several applications. We tested the alignment data with the commercial software *ProVI* (Obermeyer, 2018) and the *FZK-Viewer* (Karlsruher Institut für Technologie, 2019). The latter one is already capable of processing *IfcLinearPlacement* entities.
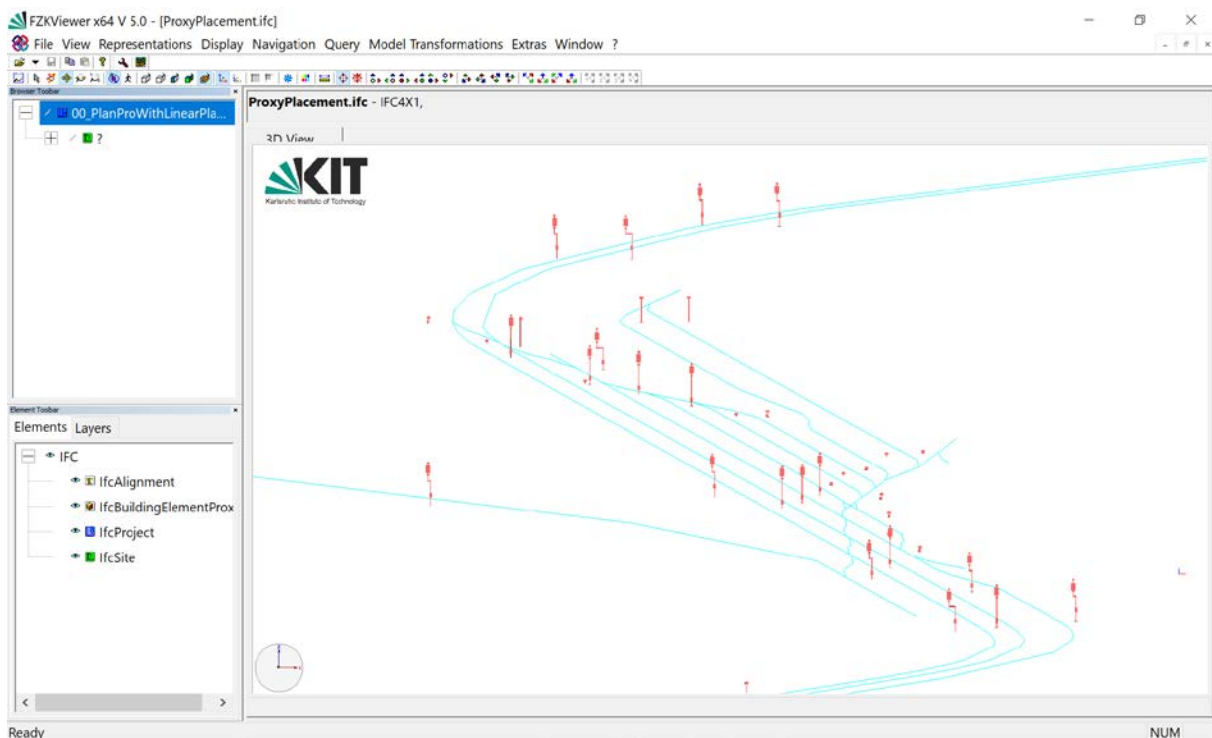

Figure 3: Resulting IFC Model based on IfcAlignment and IfcLinearPlacement

3. Discussion

The paper has presented two different approaches for integration domain-specific information models into a common model representing the overall railway project by means of the vendor neutral data format IFC. Both approaches presented the feasibility to convert domain-specific data models into an IFC model. By using the *IfcAlignment* classes as well as the *IfcLinearPlacement* concept, it is possible to set up an IFC model based in semantically powerful IMs, which uses alignment expressions for the overall project orientation. The concept of property sets enriches the data schema and provide the flexibility to adapt the model to specific needs. The presented approach of mapping semantically powerful but geometrically sparse IMs into IFC can be applied to many existing data concepts which are used for domain-

specific exchange scenarios. By converting them into IFC models, it is now possible to coordinate elements and their related attributes across different domains. However, the translation and analysis of PlanPro have unveiled significant limitations: The geometric granularity of arrangement drawings can only provide an estimation of the component's shape to be built in the real world. Thus, the modeled geometry can differ from real product shape in the built environment, and this must be considered when performing simulations based on the shown IFC models. In order to use the created models on site, refinements of the used geometric representations are inevitable. In conclusion, the proposed mapping process is possible and enriches the concept of seamless collaboration and communication along different domains in a project.

IMs often provide fictive components, which do not have any geometric representation but are of high importance for the design process. Such concepts cannot be directly covered by the IFC schema yet but are depictable in an IFC model. The use of placeholder geometries like cuboids or other simple geometries is one possible solution for such issues. The obligation that every class derived from *IfcProduct* must have a *ProductRepresentation* is restrictive in that point but solvable.

User-defined property sets enrich an IFC model due to project or domain-specific requirements. However, the possible data types for property values are limited to simple numeric or textual types and Booleans. An IM can have much more specialized subclasses, which structure relevant attributes and relationships better than a simple *IfcPropertySet* can do. Thus, use cases are conceivable that could be better served with the original IM. The focus of our research was the preparation of data for project-wide communication rather than supporting advanced and specialized use cases. Another option inside the IFC schema is the use of element assemblies, which should be addressed in future research.

Due to the yet missing standardization of railway components in IFC, it is complex to define filters or to process the models in subsequent simulations. It is possible to filter specific components by their names, but the defined filters are dependent on modifiable attributes. A better approach is the detection of elements by their element type. However, the necessary changes in the implementation described in Section 2 will not have a massive impact: most of the IFC classes representing railway equipment components will probably derive from *IfcProduct*.

In summary, the proposed conversion from IMs into the IFC format can be used to utilize domain-specific information in federated models and combine those in a coordination model. However, limitations exist with respect to the granularity and expressiveness of the converted data.

4. Summary

In this paper, we showed different approaches to convert domain-specific data formats into a more generic data model. These concepts offer much flexibility when querying data in a model and using it for in cross-domain simulations.

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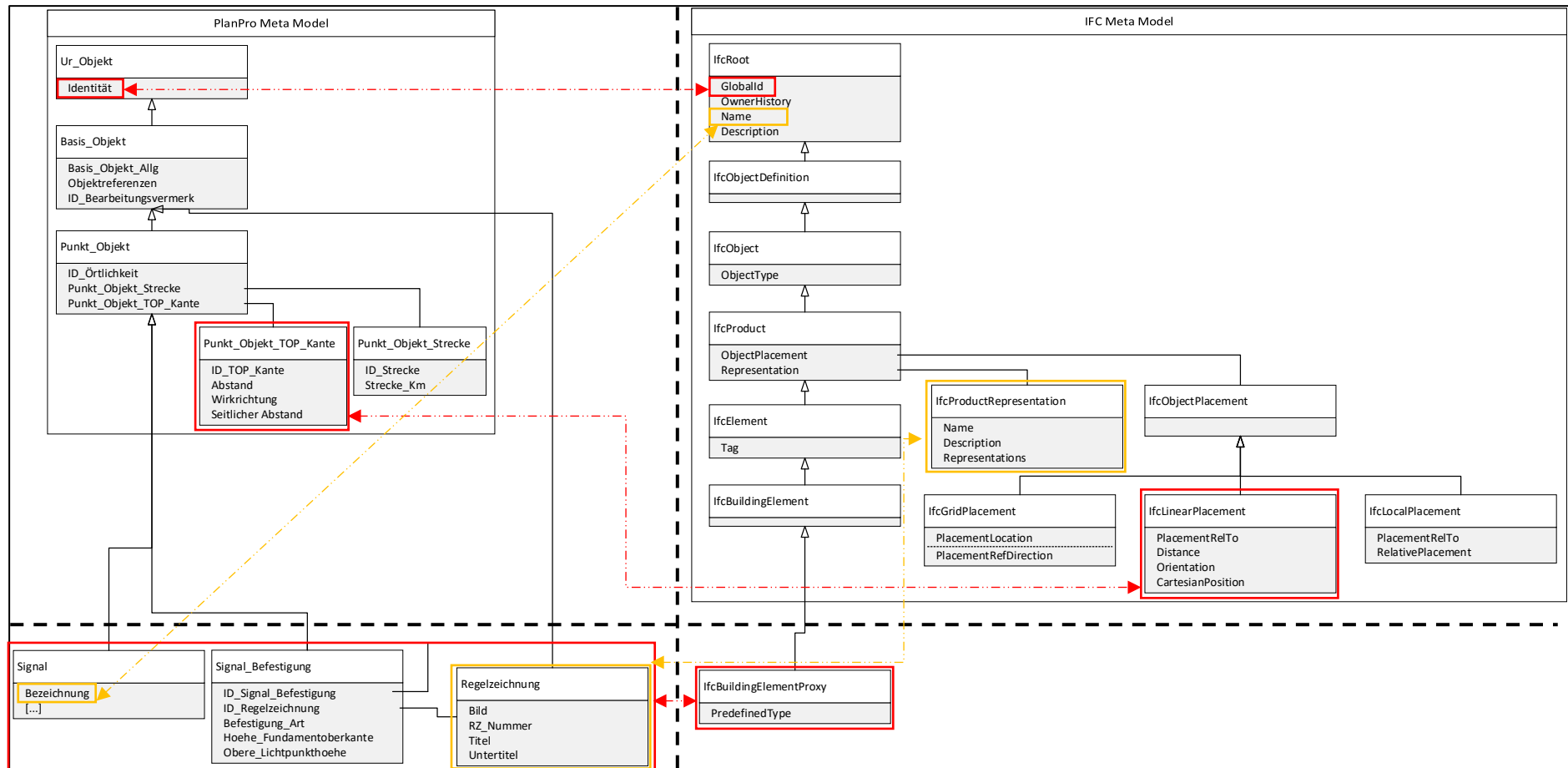xBIM Toolkit. (2019). Retrieved February 12, 2019, from http://docs.xbim.net/

Figure 4: Possible Correlation Graphs between PlanPro (left) and IFC (right)