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Systematic Evaluation of the IFC Data Model for Infrastructural Assets and BIM Use Cases

Master Thesis

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Abstract

Building Information Modeling (BIM) is applied in a growing number of infrastructure projects due to benefits such as increased efficiency and quality. Construction projects with BIM are carried out through a variety of domain-specific software, which requires a complete and accurate data transfer between the tools. Due to its public funding, a vendor-independent approach is essential in transportation infrastructure projects. Consequently, the market demands a holistic approach for a vendor-neutral format that supports the exchange of geometric and semantic data adapted to infrastructure assets. To target this goal, the ISO-standard 16739-1, which contains the schema of Industry Foundation Classes (IFC) addressing the buildings sector, will be replaced by the new version of IFC4x3 in 2023 that has been extended to meet the requirements of transportation infrastructure facilities. Until now, research has not focused on comparing the previous most common version (IFC2x3) and the new (IFC4x3) release at the scale of data modeling in practical projects. This work addresses this scientifically uncharted task in two steps. The first part compares the documentations of IFC2x3 and IFC4x3 concerning their definitions related to infrastructure assets. The second step contains a case study involving the metro line project Ümraniye-Ataşehir-Göztepe in Istanbul. In the scope of this work, an evaluation tool is developed to investigate how information is generally represented in the IFC2x3 models. Parts of a tunnel model are remodeled, then exported to IFC4x3 and finally reanalysed using the developed tool. The results show improvements with IFC4x3 in object placements, semantics implementation, geometric representation as well as a higher flexibility in the hierarchic structure. This leads to an enhanced basis for downstream tasks in the BIM process, but requires adaptations in software and expertise among users.

Zusammenfassung

Building Information Modeling (BIM) wird bei einer wachsenden Zahl von Infrastrukturprojekten angewandt, da sie Vorteile wie eine höhere Effizienz und Qualität bietet. Bauvorhaben werden in BIM mit einer Vielzahl an fachspezifischen Programmen umgesetzt, was einen vollständigen und präzisen Datenaustausch zwischen den Programmen erfordert. Da Verkehrsinfrastrukturprojekte öffentlich finanziert werden, ist ein herstellerunabhängiger Ansatz in diesem Bereich von wesentlicher Bedeutung. Aus diesem Grund verlangt der Markt nach einem ganzheitlichen Ansatz für ein herstellerneutrales Format, das den Austausch von geometrischen und semantischen Daten unterstützt sowie auf die Anforderungen von Infrastrukturprojekten abgestimmt ist. Mit diesem Ziel wird die ISO-Norm 16739-1, die das Schema der Industry Foundation Classes (IFC) für den Gebäudesektor enthält, im Jahr 2023 durch die neue Version IFC4x3 ersetzt, die um die Anforderungen von Verkehrsinfrastrukturanlagen erweitert wurde. Der Vergleich zwischen der bisher gebräuchlichsten Version (IFC2x3) und der neuen Version (IFC4x3) auf der Ebene der Datenmodellierung in praktischen Projekten war bisher nicht Fokus der Forschung. Genau diese Fragestellung wird in der vorliegenden Arbeit in zwei Schritten behandelt. Im ersten Teil werden die Dokumentationen von IFC2x3 und IFC4x3 in Bezug auf die Eignung für den Bereich der Verkehrsinfrastruktur verglichen. Der zweite Schritt ist eine Fallstudie, die sich auf die U-bahnlinie Ümraniye-Ataşehir-Göztepe in Istanbul bezieht. Im Rahmen der Arbeit wird ein Evaluierungstool entwickelt, auf dessen Grundlage die allgemeine Darstellung von Informationen in den IFC2x3 Modellen untersucht wird. Zusätzlich werden Teile eines Tunnelmodells nachmodelliert, dann nach IFC4x3 exportiert und schließlich mit dem Tool neu analysiert. Die Ergebnisse zeigen Verbesserungen durch IFC4x3 bei der Objektplatzierung, der Semantikimplementierung, der geometrischen Darstellung und eine erhöhte Flexibilität in der hierarchischen Struktur. Dies schafft eine verbesserte Datengrundlage für die nachfolgenden Anwendungen im BIM-Prozess, erfordert aber Anpassungen in Software und Fachkenntnisse bei den Anwendern.

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List of Abbreviations:

AEC	Architecture Engineering Construction
API	Application Programming Interface
BEP	BIM Execution Plan
BIM	Building Information Modeling
bSI	buildingSMART international
CDE	Common Data Environment
EIR	Exchange Information Requirements
IDM	Information Delivery Manual
IFC	Industry Foundation Classes
IMM	Istanbul Metropolitan Municipality
LOIN	Level of Information Need
MEP	mechanical electrical plumbing (engineer)
MVD	Model View Definition
TBM	Tunnel Boring Machine
ÜAG	Ümraniye-Ataşehir-Göztepe Metro Line Project Istanbul

1 Introduction and Motivation

Technology improvement is a target across all industry sectors, leading to modern solutions. The resulting complex systems require a solid basis of technical regulations and standards to support their functionality in a wide range. (Tasseey, 2017) An example of this is the Bluetooth development. Within the first release by a consortium of different companies in 1999, the developers struggled to connect devices from different vendors. Nowadays, the technology works with an interoperability between devices of numerous vendors, in a low energy mode, in a long range up to 200m, with direct pairing, location-relevant navigation and efficient data transfer. Specifications defined by the Bluetooth Special Interest Group (SIG) deliver technological-based modules that can be used all over the industry to ensure interoperability within the devices. (bluetooth SIG, 2022; LTE Anbieter, n.y.) A comparable progression that is taking place in parallel is the IFC exchange format development in the AEC industry. This process has also taken place for over 20 years, and builds an important component of BIM (Building Information Modeling). Also in this field, specialists develop standards and guidelines, to advance the application of the concepts. In this case, there was an improvement in technical solutions, but BIM is still on its way to a smooth and flawless application in the industry.

1.1 Introduction

The application of BIM in a growing number of projects demonstrates the benefits of this method over classical paper-based design of built facilities. Numerous cases show that implementing BIM increases quality, coordination, and collaboration processes within a project while decreasing costs and time (Saniye Oktem et al., 2018). Furthermore, it provides information about the design and makes this data available for all stages of the object's lifecycle (Pasetto et al., 2020). In the best case, through an interdisciplinary clash detection, clashes and inconsistencies can be detected during the planning phase before the construction. This leads to less resource demands by avoiding defects and overproduction through planning errors. As an example, within one of the biggest airport projects planned with help of BIM, more than 2 billion Euros and a

couple of years of delays could be prevented while planning the Istanbul Airport with help of BIM (Akarcalı & Ergen, 2020).

Although the benefits of BIM have been experienced by the industry, it is still a challenge and a long-term goal to find and spread a common technical solution for process implementation of civil infrastructure projects that includes alignment-based projects. (Ait-Lamallam et al., 2021), (Kwon et al., 2020) This delay in development is identified for many years now and is frequently discussed in the literature. Results show that some of the main problems are interoperability, data transfer (Saniye Oktem et al., 2018) and missing opportunities to model infrastructure-specific components (infrastructure libraries) (Pasetto et al., 2020), and an insufficient framework for information governance (Bradley et al. 2016) (S. A. Biancardo et al. 2021).

To deal with these interoperability problems, new versions of data exchange formats are developed by buildingSmart international (bSI) to standardize the data interface with the IFC (Industry Foundation Classes) data model. The latest development release of IFC4x3 aims especially for infrastructure projects (Borrmann et al., 2021a) and is close to becoming the new version of ISO 16739 (expected for early 2023). (buildingSMART Deutschland, 2022)

1.2 Research Hypothesis

Even though several release candidates of the IFC schema have been made publicly available throughout the last years, no scientific publication has evaluated how much the new standard can contribute to better information transfer in projects with infrastructure assets. The new IFC release should, in the best case, provide an enhanced basis to perform project process management in the field of transportation infrastructure. Hence, the thesis at hand aims to evaluate if the new release (IFC4x3) provides a simple and effective basis for process implementation and thus improves the quality of the model.

1.3 Structure of the Thesis

In chapter 2, the thesis will give a broad review of BIM in infrastructure projects in general. It will contain an overview of the state of the art using BIM-technology in Germany and Turkey and establish basic definitions of the BIM-based process management, including the information delivery.

Furthermore, a literature review on the development of the IFC schema will be given. In particular, to work out the differences between the versions IFC2x3 and IFC4x3, both documentaries are analysed on a basic entity level and determined which of the adaptations from IFC2x3 to IFC4x3 play an important role for infrastructure assets. The knowledge gained in this part will provide the basis for the development of a tool that extracts model data according to its hierarchy, semantics, placement structure and geometric representation.

The evaluation tool is applied to models from the Ümraniye-Ataşehir-Göztepe (ÜAG) metro line project in Istanbul. The outcomes of the evaluation of two station and one tunnel model in IFC2x3 are analysed in chapter 4.3. Potential improvements of the tunnel model through IFC4x3 are discussed in chapter 5.

2 Literature Review BIM in Infrastructure

2.1 Current Situation in Turkey

In Turkey, most of the BIM-based projects belong to the sector of infrastructure (Saniye Oktem et al., 2018). Istanbul Metropolitan Municipality (IMM) is the biggest national driver with more than 130 km of metro construction projects planned with help of BIM (Saniye Oktem et al., 2018), (UNECE, 2021). In 2019, Istanbul got announced by the International Association of Public Transport (UITP) to be the leading city in the world with the highest number of rail system construction projects at the same time with 19 ongoing projects (A. Akcamete et al., 2020). As the Department of Rail Systems started tendering infrastructure projects with BIM very early, huge metro lines are planned BIM-mandated since about 2014 (A. Akcamete et al., 2020; Saniye Oktem et al., 2018).

Although these projects are running for many years now, the experience gained has only been gathered and analyzed in few research works up to now. Recently, Akgüneş Ahmed (2022) has analysed the main barriers concerning BIM implementations. She names as main problems for the further implementation process of BIM in infrastructure the need for international standards, legal and political issues and the lack of trained employees concerning BIM. Even though, graduate students are educated at the universities in the field of BIM and there are specific programs for professionals to become BIM specialists available, there is still a need for skilled professionals. Consequently, this leads also to a barrier for companies to form their BIM strategy to adopt the new methods. Supplementary, if there are no national standards defined, the barrier to develop project-specific or company-specific guidelines and strategies is even higher. According to Akgüneş Ahmed (2022) several steps should be taken to improve the situation, such as carrying out pilot projects by the state to gain experience, BIM education starting from an undergraduate degree, enlarging BIM teams and changing organisational structures towards the need for BIM implementation.

2.2 Current Situation in Germany

In Germany, similar problems were identified in the implementation process of BIM. P. Both (2012) names among others standardisation in contracting, improvement of the neutral IFC format and higher focus on BIM related education at universities as main

components for an improvement in the BIM implementation. Within the last years, the following steps were taken by the government and the private sector to push the field of BIM.

The development of BIM in infrastructure on the contractors point of view is organized as followed: The Federal Ministry of Transport and Digital Infrastructure (BMVI) released different papers to implement the BIM-Method. The first one is a step-by-step plan from 2015 to 2020. It contains a large number of trial projects to gather experiences that are shared widely. (BMVI, 2015) Based on these outcomes, in 2021 the BMVI published a master plan for successive development of the nationwide implementation of BIM in road construction until 2025 within three phases and with more and more standardised use cases being added in each phase. (BMVI, 2021) A similar paper has been published by the German Railways (DB). Entering the third phase of the plan, which includes a standardized application of BIM for all projects is a goal until 2025. Since the current government in Germany has set the goal of halving the duration of infrastructure projects in the coalition agreement until 2025, BIM in infrastructure will gain in importance. (DB AG, 2022)

The explained approach concerning BIM in infrastructure leads to a corresponding reaction in the industry. In Borrmann et al.(2021c) several companies explain their BIM strategies and share experiences gained in the projects. Companies discovered an increase in efficiency through BIM. For instance, the designers benefit from an enhanced communication between the domains through 3D models, since the design can be communicated clearly on a visualised basis. (Hochmuth et al., 2021) Design companies are adjusting their work methods to reach the requirements of the BIM-mandated projects. Schüßler-Plan, for instance, integrated a team of experts, which spread the BIM-Know-How over the company. An internal academy was formed to train their employees in both, basics in BIM-related topics and software-specific application. (Baden-Wassmann & Bach, 2021) A similar approach for an internal training system is described by the company HOCHTIEF (Schumann & Godawa, 2021).

Private companies are involved in the process of developing guidelines for BIM utilization. The design company OBERMEYER intends to participate actively in the development process of BIM. (Hochmuth et al., 2021) It is beneficial that companies test and

optimize the ideas in practical utilization and get involved further. (Markus König)¹ This is why they act as partners in governmental consortiums such as “BIM4INFRA2020” or currently “BIM Deutschland”. Many members of buildingSMART Deutschland are private design companies. (BIM4INFRA2020; BIM Deutschland - Partner; buildingSMART Deutschland)

Through the pilot projects, the government took the first steps towards a standardisation of the BIM process. This will gradually provide in the basis for companies to create guidelines for their specific processes.

2.3 BIM-based Process Management and Information Delivery

The following section establishes basic definitions of the BIM process in general, analyses the information delivery process with its technical implementation and outlines the envisioned approach to information delivery in the future.

The idea of Building Information Modeling (BIM) encompasses processes and technologies aiming to design, construct and operate a facility throughout its entire lifecycle collaboratively with various parties involved (BIM Dictionary, 2021). Construction projects with BIM are carried out through a variety of domain-specific software. In advance, the client specifies the Exchange Information Requirements (EIR), which are part of the contract documents. The contractor’s response to the EIR is the BIM Execution Plan (BEP), which describes how the information delivery for the defined BIM objectives will be achieved. (Klusmann et al., 2020; Krischler et al., 2021)

2.3.1 IFC

buildingSMART international (bSI) develops standards to support the consistent utilization of BIM. In order to provide interoperability within several steps of the BIM process, the Industry Foundation Classes (IFC), an object-oriented schema to implement a digital description of the built environment, are introduced. The concept of IFC is defined in the ISO 16739-1 (2018) standard (ISO.org). (bSI - IFC release notes; Kwon et al., 2020)

¹Indirect quote from www.schuessler-plan.de/de/wissen/digitale-vernetzung/BIM, accessed 18.11.2022

2.3.2 bSDD

The buildingSMART Data Dictionary (bSDD) is a service by bSI that builds a platform to store information as classifications with their properties and specifies them by allowed values, units and translations (bSI - bSDD). By a single-entry point it combines multiple dictionaries and can be accessed through API (Klusmann et al., 2020). This builds a strong solution to enhance the semantic information delivery within a model (Tomczak et al., 2022).

2.3.3 Use Case

BIM use cases describe common workflows of BIM models (Krischler et al., 2021). In detail, they define who provides which information, at what time, in which format and in which level of detail (IFC Rail Project, 2019). The use cases specify the purpose of the models. Examples of use cases are stock modeling, visualisation, coordination of discipline models, derivation of 2D plans from the models, or quantity take off. Usually, the definition of the use cases determines an elaboration level of a model that has to be fulfilled at a specific time. Therefore, standardising the demanded use cases leads to a uniform usage of BIM. This is why many organizations are working on introducing standards in this field. (BIM Deutschland, 2022; ARGE BIM4RAIL, 2020)

Within the first trial projects in Germany, it was experienced that too many use cases within a project are not reasonable (André Borrmann et al., 2017). With this understanding gained, the German Railway (DB Netz) decreased its number of use cases from initially 28 to 19 (Forsmann & Klar, 2021). In particular, the following adaptations were applied to the use case management of the DB: Very specific use cases, such as “usage of modern site logistics” or “date-specific earned-value analysis” are omitted, use cases related to file management are aggregated and task from the process management, such as “development of a BEP” are not especially implemented as use cases. (DB Netze; König et al., 2019)

In 2022, BIM Deutschland (the national BIM competency centre led by a consortium of the Federal Ministry for Digital and Transport and the Federal Ministry of Housing, Urban Development and Construction) published a list of 21 standardised use cases (BIM Deutschland, 2022). This list aims to form a basis for a common BIM implementation in Germany over the domains of road, water ways, rail and buildings. In addition, the document of the standardised use cases includes a template that leads through the

most important steps of the implementation process. It ensures that each use case is assigned to a specific project phase and that the benefit and requirements of the use case are clarified. Additionally, details of quality criteria, persons involved and relations to other use cases should be specified. (Thomas Liebich et al., 2022)

This also meets the proposal that contractors should receive support for producing the models. As the use cases are part of the Employers Information Requirements (EIR) and therefore determine parts of the contract documents, utilising guidelines for the EIR could be beneficial. Using EIR-compliant templates leads to a higher efficiency, a simplified approach and consequently less errors in the model creation process. (Borrmann et al., 2021b; Klusmann et al., 2020)

In Turkey, no information about standardised use cases has been published yet. However, A. Akcamete et al. (2020) identified this gap and look for an approach to determine standardised EIRs for metro projects in Turkey, as they have been BIM-mandated for many years. Within the scope of their study, they analyse three international EIRs, compare the contents and derive suitable templates for the projects in Turkey. Concerning the BIM use cases in the EIRs, the most suitable version is a combination of Employer-mandated use cases and project-specific use cases. This concept could be a matching template for the metro projects in Turkey, as some use cases are needed for all projects, and others are project specific.

2.3.4 Process-Based Model Information Exchange

As explained above, the use cases describe the purpose of the models. These ideas form the fundamentals of each project's individual BIM implementation process. As the BIM method comprises a variety of software solutions, information must be exchanged between different software. Consequently, the information exchange process is also calibrated to the demanded use cases. The technical realization of this procedure is explained below.

Information Delivery Manual

Since the entire IFC data model is too large for effective and discipline-specific data exchange buildingSmart international developed the IDM/MVD method that defines who shares information when, how, for which purpose, and between which participants (Tomczak et al., 2022; Beetz et al., 2021). Within this method, the Information Delivery

Manual (IDM) defines the common quality and information requirements, which builds the domain-specific requirements. The structure of an IDM is shown in

Figure 1. An IDM is involved with the goal of fulfilling one task that builds up a use case (UC) identified by experts. The procedures and steps that are needed to fulfil the use case are visualized in a process map (PM). Information required for a specific process is stored in the exchange requirements (ER). (Beetz et al., 2021)

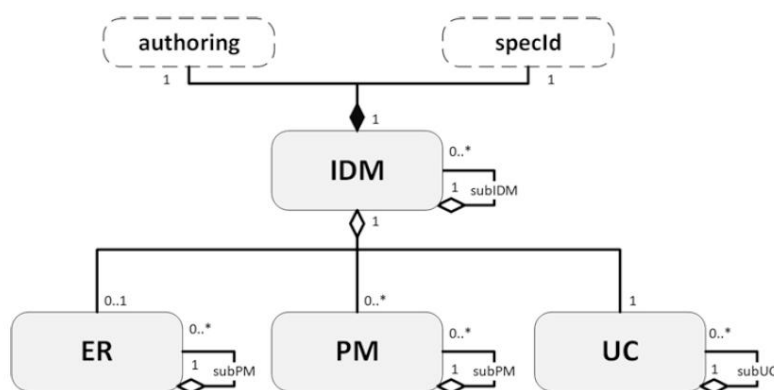


Figure 1: Structure of an IDM (Beetz et al., 2021)

Model View Definitions

The Model View Definitions (MVD) build the response to the IDM. It takes the information formed in the IDM as a basis and provides the technical requirements for the domain-specific IFC model. It is the solution by bSI to check if IFC models correspond with a predefined model view to ensure interoperability through different software and implementation variety. A MVD defines the parts of an IFC structure that will be used to deliver the information needed. (Beetz et al., 2021) The main purpose is to reduce the large model and to use only a subset of the whole model that is needed for the use case (Chi Zhang et al., 2013).

mvdXML

MVDs are accessed within the BIM method using the machine-readable mvdXML format. An mvdXML document stores Templates and Views.

A Template contains a list of concept templates (Chipman et al., 2016). Concept templates specify how entities of the IFC schema should be assembled for a specific scenario. It defines a path through the IFC schema towards a piece of information needed

for the ER and gives the subtype of the IFC definition that is required to describe the scenario. *Figure 2* depicts an example of the case that the construction type of a door is a requirement in the ERs (e.g for the use case Quantity Takeoff). The path of a concept template through the model leads to a set of entity and attribute rules, which build the structure described in the following example. The definition starts with the root entity *IfcElement* (*Figure 2*). This entity is the starting point of several definitions of the attribute rules. One attribute rule in this example is *IsTypedBy*, followed by the entity rule of *IfcRelDefinesByType*. The next attribute rule is *RelatingType*, which leads to the entity rule *IfcElementType*. The attribute *ElementType* is the end of this path and delivers the construction type of the door. (Chi Zhang et al., 2013) These rules are implemented in the Template part of the mvdXML document.

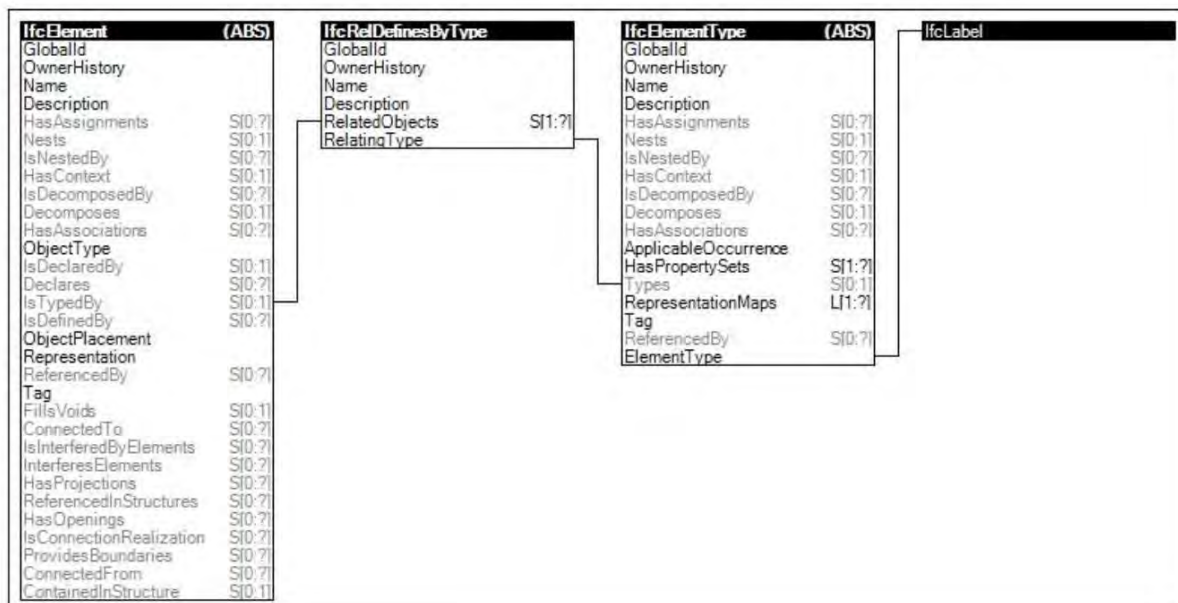


Figure 2: Example Concept Templates: Identification and ElementType (Chi Zhang et al., 2013)

The sub-part Model View within a mvdXML defines the use of a concept template within a specific view. It consists of information about the applicable schema, the base view, a list of ERs and ConceptRoots. (Chipman et al., 2016)

A list of exchange requirements defines a collection of IFC entities and properties that are needed for the use case. To give an example, this could be the construction type of all objects utilized in the model to fulfil the use case of a Quantity Takeoff. (bSI -MVD policy for IFC 4.x, 2021; Chi Zhang et al., 2013)

ConceptRoots are applied to a specific entity of the IFC schema. It defines how the concept templates and exchange requirements implemented above are applied in a specific view. Therefore, a concept consists of references to the corresponding concept templates and to the exchange requirements (c.f. [Figure 3](#)). The third component are TemplateRules, which build a tree structure of rules depending on each other by Boolean logic. The concept is valid only if the outermost TemplateRule is set to TRUE. (Chipman et al., 2016)

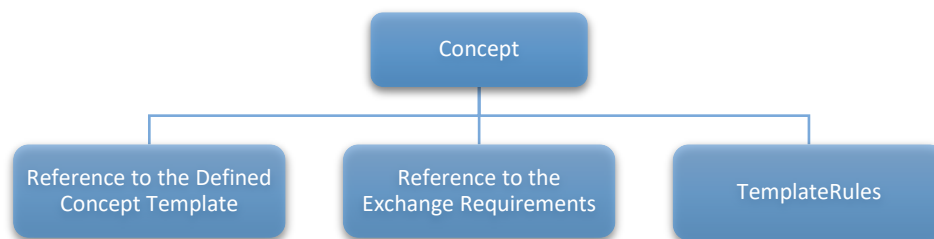


Figure 3: Components of a mvd:Concept

Base MVDs

When software applications use their own solutions for MVDs it leads to a loss of interoperability. This may cause limitations in software application options and problems reading data by a software tool that uses a different MVD than the software from which the data was exported. Additionally, it is an enormous effort to implement each MVD individually. (bSI -MVD policy for IFC 4.x, 2021) To sum it up, MVDs lose their interoperability if concept templates or resources are not used consistently in their implementation.

These are the reasons why bSI delivers the solution of base MVDs, where concept templates and the selection of entities of the IFC schema that should be used are set and should not be edited. In addition, no extensive exchange requirements should be added. bSI strongly recommends using the common base MVDs and extending this basis through domain-specific exchange requirements, which have to be approved by b-cert bSI's certification platform. (bSI -MVD policy for IFC 4.x, 2021)

To date, there are MVDs predefined for IFC 2x3 version. These include the coordination view that coordinates the data exchange between architecture, structural and technical services domains. Another example is the structural analysis view to work with loads and the physical model. Through the years, other MVDs have been added as the Reference View or the Design Transfer View. (Beetz et al., 2021) Currently, three base MVDs are officially implemented in IFC: Coordination View (for IFC2x39 / Reference View for IFC4.x), Alignment based Reference View (for IFC4x3) and the Design transfer View. (bSI - MVDs Today)

Moreover, MVDs form an opportunity for automated quality assurance of IFC data, and it provides a basis for software certification. The long-term goal of the IDM/MVD method is to gain a foundation through implementing common scenarios that become international standards and can be used as basis. The base MVDs can be extended by each administration or nation depending on their individual requirements to deliver a solution for heterogeneous project demands. (bSI -MVD policy for IFC 4.x, 2021; Beetz et al., 2021)

2.3.5 Process-Based Model Information Exchange in the Future

Since mvdXML was developed with the idea to export full IFC models and support software certification (Tomczak et al., 2022), the experts noticed that this is not the best suitable solution for implementing exchange requirements defined by end users. Up to now, most of the processes of developing EIRs, BEPs, exchange requirements, and IDMs are not based on machine-readable or interpretable standards. This is why buildingSMART international is working on a new standard, the Information Delivery Specification (IDS). It aims to specify use case- and project-specific exchange requirements, which are machine-readable and interpretable by computers and humans. (Tomczak et al., 2022) This will improve the exchange workflow by increasing the expressiveness of exchange requirements and the reliability of the IFC data. Additionally, it supports the opportunity for clients, modellers or software vendors to validate the data (BibLus, 2021). IDS will also define the Level of Information Needs. The new idea is to use mvdXML in the “backend of software implementations, [while] IDS standards need to operate on the front-end” (bSI- Technical Roadmap, 2020b).

Figure 2 visualises how an IDS should filter the exchange requirements through all layers of the IFC data schema, including the extensions and the buildingSmart Data Dictionaries (bSDD). (bSI- Technical Roadmap, 2020b)

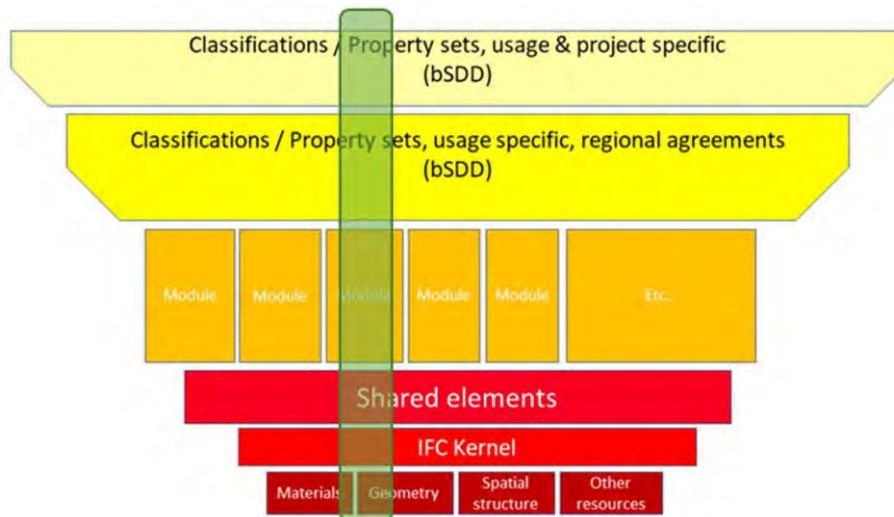


Figure 4: Information Delivery Specifications (green) as an information filter (bSI- Technical Roadmap, 2020b)

The IDS is set up by the client and can be treated as a computer-interpretable contract that defines the exchange requirements and guides the data exchange process (bSI - IDS, 2020). The idea of the IDS procedure loop can be seen in *Figure 5*. The IDS builds the solution for automatically validating the data before exchanging it. Before the model implementation process begins, the modellers can verify their software capabilities and determine whether the applications can fulfil the requirements. After the data is created and before it is exported, the modellers have the opportunity to validate it against the contract requirements defined in the IDS. If it fulfils the requirement, it can be exported to IFC with the IDS settings and sent to the client. Additionally, before accepting the data, the client can also validate the data against the predefined IDS. (bSI- Technical Roadmap, 2020a)

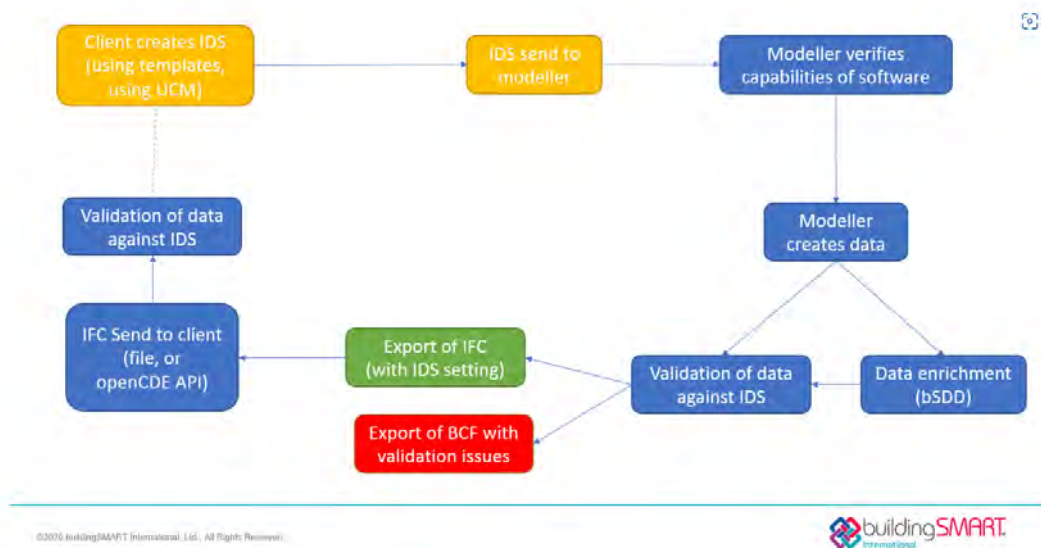


Figure 5: Circle IDS and conformance levels (bSI- Technical Roadmap, 2020a)

Another idea is to implement conformance levels between the exchange processes. This implements new constraints that IFC data can only be exchanged or combined on the same or lower level of conformance (bSI- Technical Roadmap, 2020a).

This chapter introduced several methods which are part of the BIM data exchange process. Tomczak et al., (2022) compare workflows that target integrating all aspects defined in use cases within the information exchange process. Their study covers data dictionaries, IDM/MVD, IFC property templates (further analysed in chapter 3.1.4), LOIN, and Product Data Templates (PDT). The results show that Data dictionaries (such as bSDD) are suitable for globally specified data and LOIN for project-specific data since it determines which information is needed when. IDM is beneficial when data has to be assigned to processes or workflows. Combined with MVD, it is extensible by defining new project-specific concepts. IDS is profitable for automatic compliance checking and validation of the exchange data. This research presents that the methods target different phases of the process and have advantages in various areas. None of the methods introduced covers all the aspects that are demanded within the implementing process of use cases. (Tomczak et al., 2022)

2.4 Summary Literature Review

As outlined in the previous paragraphs, the components of the information exchange and BIM process management described above interfere. BEP is connected to the EIR; the EIR depends on project-specific or standardised use cases; the IDM and

MVDs correlate and are also created based on the use cases. Therefore, the use cases influence all components in the process. This results in the high priority of the standardisation of use cases. For example, this explains why one of the first steps towards a common BIM implementation in Germany is the standardisation of use cases by BIM Deutschland.

The situation described leads to the fact that the use cases take a central position when it comes up to BIM process management, as they describe the needs of the industry. (Tomczak et al., 2022)

Therefore, it could be assumed, that if a model provides data needed to fulfil the use cases predefined in the contract documents, and the information is accessible through the BIM information delivery process, this can be an indicator for a successful application of BIM. Consequently, to refer this to the research question of this work, the new IFC version should, in the best case, provide an enhanced basis for infrastructure projects to perform simulations like visualisation, quantity take off, evaluation of design alternatives, or the generation of 2D plans based on threedimensional BIM models.

As explained above, each use case requires specific information stored and exchanged according to a design or simulation task. Thus, the success of a new schema version cannot be evaluated by a simple analysis of single entities but requires the consideration of numerous entities that form the technical implementation of the requirements defined within a use case. So, to develop a methodology that evaluates the assets of a model concerning infrastructure projects, a more profound knowledge of the entities used within the MVDs is necessary.

3 Basics to Develop an Evaluation Tool

The intent of this chapter is to outline the background principles required to implement an evaluation framework that assess the ability of a data model to provide a solid data foundation for downstream tasks. This method will address the research gap identified. Therefore, it is important to take a closer look at the fundamental concepts of the IFC data model and the changes made through the recent development periods.

3.1 IFC Schema Analysis

3.1.1 Definition and Development of the IFC Schema

buildingSMART international developed the schema of IFC (Industry Foundation Classes) as a “standardized, digital description of the built environment, including buildings and civil infrastructure” (bSI - Standards, 2022). This is a highly relevant technical progress towards openBIM (Borrmann et al., 2021a).

El-Amraoui-Farssi describes the IFC format as follows: “*The IFC format is characterized by being an object-oriented format, based on class definitions that represent objects and contain information generated throughout the life cycle of the project (from conception and design to demolition); being structured in layers with their entities, types, and relationships between them*” (El-Amraoui-Farssi et al., 2022).

The schema should be developed in an open and vendor-neutral way to provide data consistency through a variety of software. Additionally, as buildings and infrastructure assets exist for a long period, storing the data in a sustainable and long-term solution is important. A large number of public administrations all over the world tender or plan to tender their projects through BIM. To prevent preferences in any software vendor-specific exchange formats in governmental projects, a vendor-neutral solution is necessary. An independent market can be ensured by delivering through the commonly developed IFC standard. This is why the standard will gain importance in the upcoming years (Borrmann et al., 2021a).

The development of IFC has been going on for more than 20 years now. The graph depicted in [Figure 6](#) shows the evolution of IFC starting with the first version in the year

of 1997. Since then, the standard was improved in an open way. Due to a broad accessibility, there are numerous software solutions compatible with the IFC schema (Borrmann et al., 2021a). Up to now, IFC2x3 TC1 and IFC4 ADD2 TC1 (green markings) are the official versions, where IFC2x3 is the more common one. A variety of other versions never became an official standard and are considered as development steps. (El-Amraoui-Farssi et al., 2022)

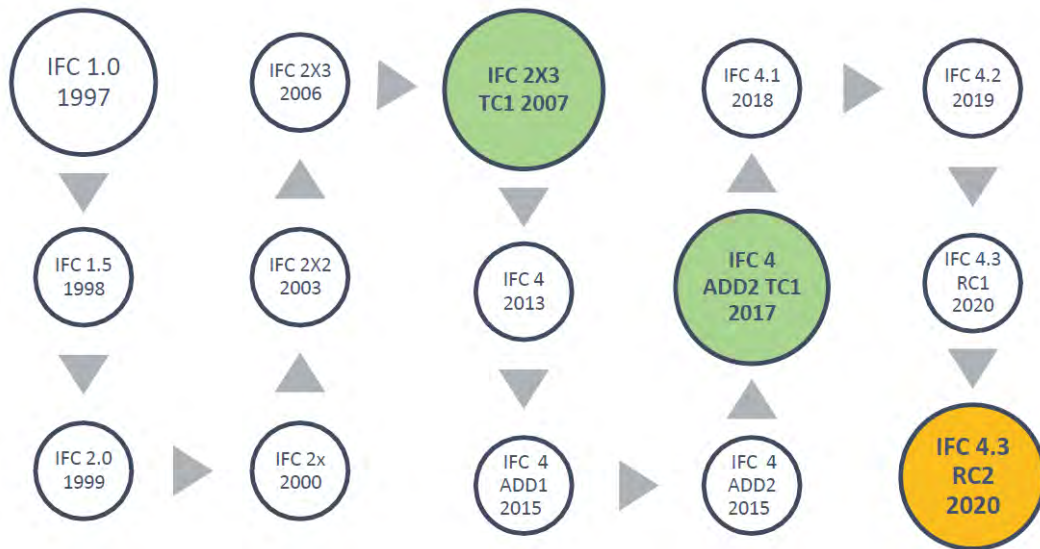


Figure 6: Evolution of the IFC versions (El-Amraoui-Farssi et al., 2022)

The current ISO standard 16739 from 2018 named “Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries” includes a data solution for buildings over their lifecycle. As the public administrations promote the BIM development in infrastructure projects (El-Amraoui-Farssi et al., 2022), the next ISO release will “extend the scope to include data definitions for infrastructure assets over their life cycle as well” (ISO.org). This is why the latest release of IFC4x3 is now a candidate for the new standard that also covers definitions for infrastructure projects and may be part of the new ISO standard in 2023. (buildingSMART Deutschland, 2022)

In this thesis, the IFC2x3 version will be evaluated in practical use in an infrastructure project and compared to the features of the new IFC4x3 release. Prior to investigate the differences between the two versions, it is important to take a closer look at the structure of the IFC data model based on the IFC2x3 version.

3.1.2 Structure of the Schema

The IFC data model is a highly complex model, which contains four conceptual layers. *Figure 7* depicts an overview of these layers. The concepts explained within this chapter are based and defined in the bSI - IFC2x3 Documentation (2020). Simple maintenance and extension of the schema are the reasons for the breakdown in several levels. (Borrmann et al., 2021a)

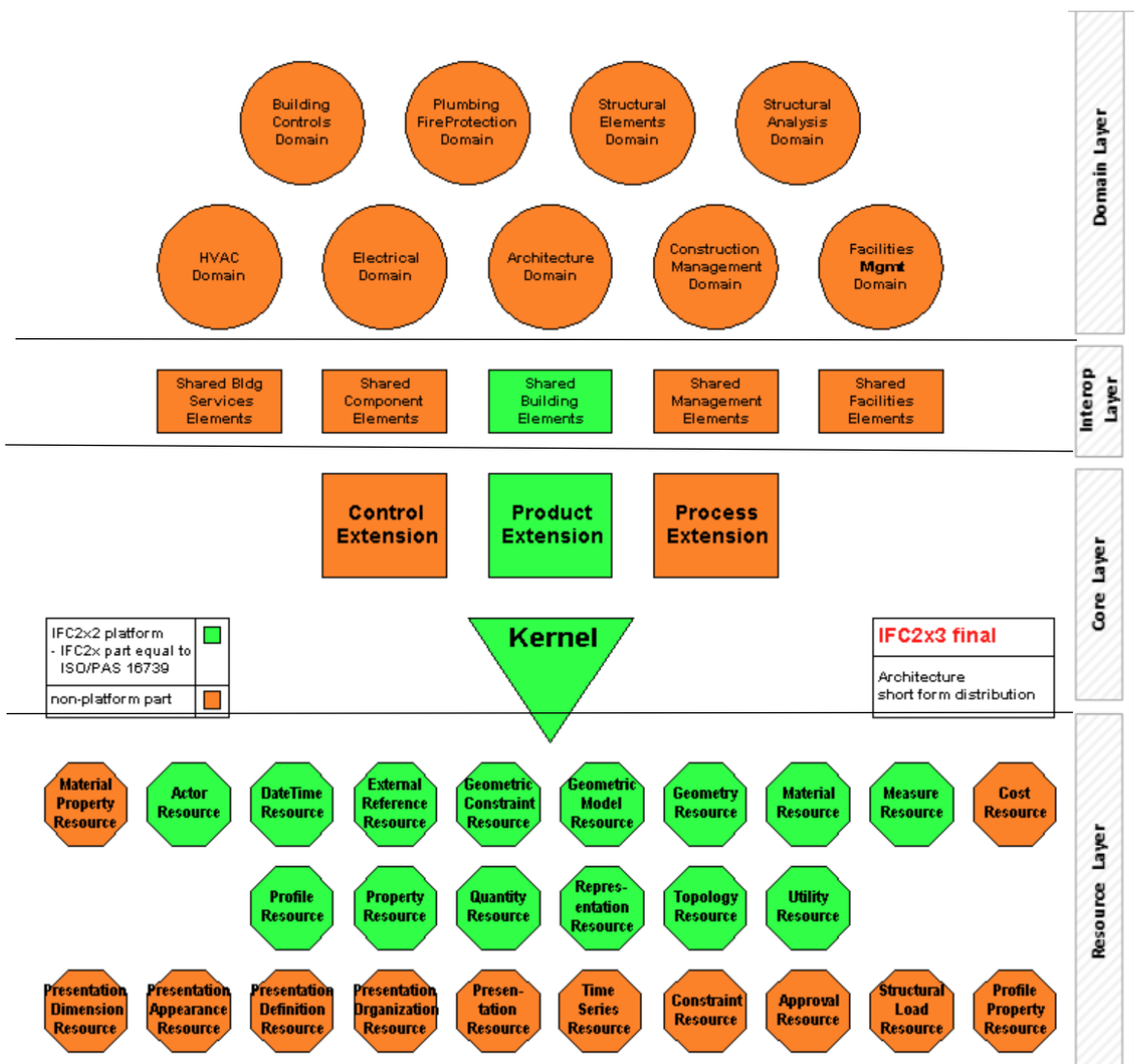


Figure 7: IFC overview structure (bSI - IFC2x3 Documentation, 2020)

The definitions of the kernel and core extension schemas build the core layer. This layer stores the most general entity definitions (bSI - IFC2x3 Documentation, 2020). Entities defined here can be referenced and used by the layers above (interoperability and domain layers).

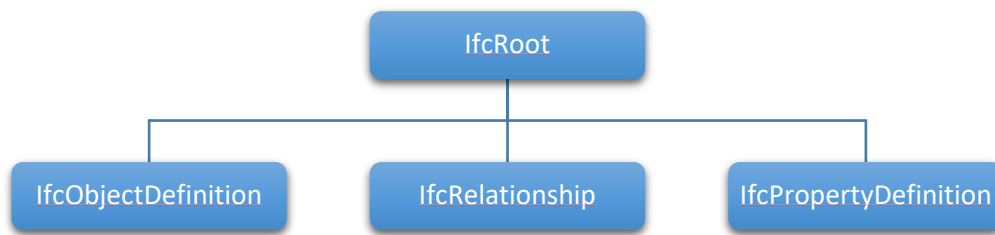
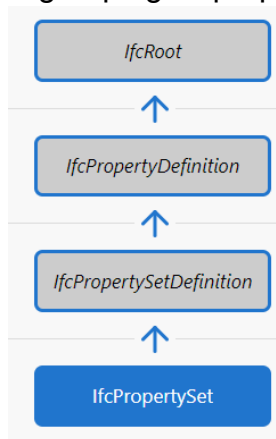


Figure 8: Structure of the first level of inheritance hierarchy

The kernel schema (IfcKernel) defines abstract basic entities. IfcRoot is the most basic entity. It allocates the globally unique identifier (GUID) as well as optional ownership and change information. Together with the three fundamental entity types IfcObjectDefinition, IfcRelationship, and IfcPropertyDefinition, it builds the first level of specialization within the entity hierarchy (Figure 8). This tree structure specifies the inheritance hierarchy of the schema and determines which attributes are transferred from one class to another class (Borrmann et al., 2021a).

An object (declared in IfcObjectDefinition) is defined as “any semantically treated thing (or item) within the IFC model” (bSI - IFC2x3 Documentation, 2020). IFC2x3 defines seven subtypes of IfcObject: products, processes, controls, resources, actors, projects and groups.

Property definitions are described as “the generalization of all characteristics that may be assigned to object definitions” (bSI - IFC2x3 Documentation, 2020). This could be a grouping of properties for example. Properties can be applied to objects by utilize



relationships (Table 1). Information that is assigned to multiple objects is stored in property definitions. A set of properties is determined in IfcPropertySetDefinition. This stores dynamically extendable properties, which can be defined through further agreements or statically defined properties, which are assigned to an existing entity definitions. IfcProperty builds the abstract superclass for all property definitions. User-defined property sets can be also defined. (bSI - IFC2x3 Documentation, 2020)

Figure 9: schema structure of property definitions in IFC2x3 (bSI - IFC4x3 Documentation, 2022)

Relationships between objects are implemented in IfcRelationship. They can be 1-to-1 relationships or 1-to-many relationships. All types of relationships are defined in Table

1. Through separating the objects from the semantic properties, it is possible to assign properties also directly to relationships (Borrmann et al., 2021a).

Table 1: Definitions of different relationship types (bSI - IFC2x3 Documentation, 2020)

assignment	is a generalization of "link" relationships among instances of objects and its various subtypes. A link denotes the specific association through which one object (the client) applies the services of other objects (the suppliers), or through which one object may navigate to other objects.
association	refers to external sources of information (most notably a classification, library or document) and associates it to objects or property definitions.
decomposition	defines the general concept of elements being composed or decomposed. The decomposition relationship denotes a whole/part hierarchy with the ability to navigate from the whole (the composition) to the parts and vice versa.
definition	uses a type definition or property set definition (seen as partial type information) to define the properties of the object instance. It is a specific - occurrence relationship
connectivity	handles the connectivity of objects.

The schema of control extension defines basic classes as `IfcControl`. This entity can control or limit other entities. This can be useful to implement, for example, rules, norms, specifications, or requirements (Borrmann et al., 2021a). The classes of `IfcRelAssociatesApproval` and `IfcRelAssociatesConstraints` are derived by `IfcRelAssociates`. These two entities provide the opportunity to connect approval or constraint information from the entities of `IfcApproval` and `IfcConstraint` to derives of `IfcControl` (*Figure 10*). The entity `IfcPerformanceHistory` inherits from `IfcControl` and delivers “the actual performance of an occurrence instance over time” (bSI - IFC2x3 Documentation, 2020). This data can be used to analyse conditions, predictions, or simulations. (bSI - IFC2x3 Documentation, 2020)

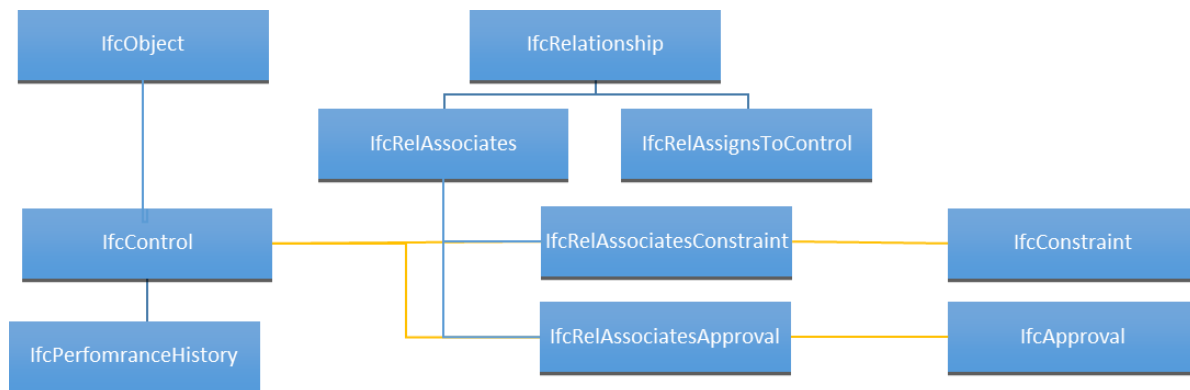


Figure 10: Overview inheritance hierarchy of `IfcControlExtension` (yellow relationships: attributes of these classes will be related for information delivery)

The process extension follows the idea to define processes in a class-based schema by the same method as product information are described by classes. This part of the schema delivers the solution to implement mapping of processes, scheduling of work including the resources needed and sharing process-based information within the IFC model. (bSI - IFC2x3 Documentation, 2020)

The core class `IfcProcess` has two subtypes `IfcProcedure` and `IfcTask`. The entity `IfcProcedure` represents “identifiable step[s] to be taken within a process that is considered to occur over zero time [and an `IfcTask`] is an identifiable unit of work to be carried out independently of any other units of work in a construction project” (bSI - IFC2x3 Documentation, 2020). These procedures are connected with the relationship `IfcRelSequence` by naming a predecessor and successor process in the attributes of `RelatingProcess` and `RelatedProcess`. Processes can also be nested by the entity `IfcRelNests`.

`IfcWorkPlan` and `IfcWorkSchedule` inherit scheduling information from their abstract supertype `IfcWorkControl`. From this basis, work plans can be derived. Task schedules in a work plan or schedules for different domains or topics can be developed with help of `IfcWorkSchedule`. (bSI - IFC2x3 Documentation, 2020)

The product extension gives the physical and spatial description of an entity including the relations to other entities. Products are described in subtypes of `IfcProduct` as for instance `IfcAnnotation`, `IfcElement`, `IfcPort` or `IfcGrid`. For example, the entity `IfcPort` forms the basis to connect elements to each other through the relationship `IfcRelConnectsPorts`. Additionally, it delivers the spatial decomposition project structure. (bSI - IFC2x3 Documentation, 2020)

The interoperability layer contains entity definitions that are applied across several disciplines. It is used for the exchange of information between different domains and for sharing construction information. Entities from the core layer are derived and can be utilized in several use cases. It poses a connection between the basic kernel and the domain schemas of the model. (Borrmann et al., 2021a) It consist of the entity `IfcSharedBldgElements` that provides the subtypes of `IfcBuildingElement` to deliver geometric use definitions for the elements. `IfcSharedBldgServiceElements` builds the basis to interoperate between the Building Service domain extensions (`IfcHavacDomain`, `IfcPlumbingFireProtectionDomain`, `IfcElectricalDomain` and `IFCBuildingsControlDomain`). `IfcSharedComponentElements` gives the opportunity to implement small components as accessories or fasteners and `IfcSharedFacilitiesElements` builds up a schema connected to `IfcProcessExtension` and `IfcSharedMgmtElements` that supplies data and information needed in the field of facility management. In addition, `IfcSharedMgmtElements` is used for, among others, cost schedules and links to information about purchase, change or work orders. (bSI - IFC2x3 Documentation, 2020)

The domain layer is the highest layer. It describes entity definitions, which are specialized in a certain discipline. As they build the end in the hierarchical concept, they can not be referenced by layers or other domain schemas (El-Amraoui-Farssi et al., 2022).

The resource layer builds the lowest layer containing individual resource schema definitions (bSI - IFC4x3 Documentation, 2022). Entities defined here cannot be independent stand-alone elements, because the definitions do not include a globally unique identifier (GUID) as they are not derived from the kernel entity `IfcRoot`. They can be used over the entire model (Borrmann et al., 2021a). For better understanding, the following examples are given: External sources as classifications or libraries are organized within the entity `IfcExternalReferenceResource` and can be used within the model. `IfcGeometricConstraintResource` delivers the different types for object placements and `IfcGeomtryResource` includes the definitions for geometric representations.

If the entity instances are assembled in a model, different application scenarios arise. This practical fields can be named as hierarchy, semantics, placement and geometry. They are explained in detail below:

Hierarchical and Structural Composition

A fundamental part of the implementation of projects by the IFC schema are the hierarchic levels through their composition relationships (Borrmann et al., 2021a). A typical composition structure of an IFC model (2x3) can be described as following:



Figure 11: composition structure IFC2x3

The IfcProject is decomposed by the IfcSite, IfcSite is decomposed by the IfcBuilding and the IfcBuilding is decomposed by the IfcBuildingStorey(s). IfcBuildingStorey contains or is referenced by elements, which are located within the storeys. This basic concept is explained in Figure 12.

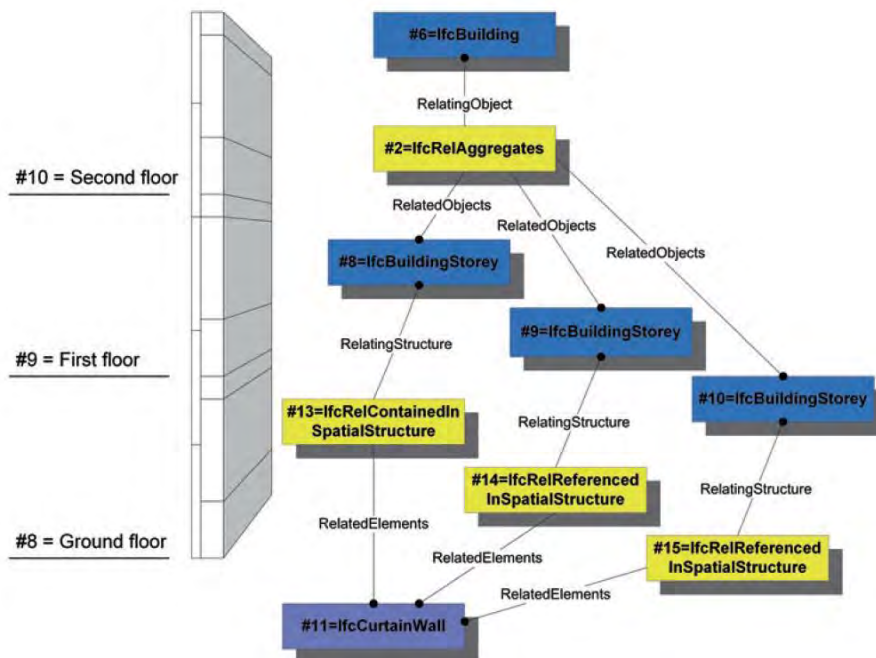


Figure 12: sample aggregation structure of a building including the corresponding relationships (Borrmann et al., 2021a)

Implementation of semantics

To protect the schema from overloads, the semantics are split up in different implementation types. Some basic information about objects are directly attached as attributes to the entity definition and thus a static part of the IFC schema. For maintaining flexibility between different standards and requirements a second way of semantic information delivery is implemented. Through the subtypes of `IfcProperty`, user- or pre-defined information can be connected as name-value pair to the schema. Within IFC2x3 single value properties can be grouped within `IfcPropertySets` and assigned through the relationship `IfcRelAssignsProperties` to one or many objects. To pretend error prone differences in the naming strategy for property sets, bSI offers a large number of standardised property sets. (Borrmann et al., 2021a)

Placement

A definition of `IfcObjectPlacement` has to be applied on each product that has a shape representation. Within IFC2x3, there are three types of object placements: Absolute placement is a placement absolute in the global coordinate system. Relative placement means an object is placed relative to the object placement of another product. A placement relative to virtual intersections and a given direction is named grid placement. The `IfcGridPlacement` receives through its first attribute the virtual grid intersection, where the representation should be placed and through the second attribute the orientation of the shape by another grid intersection. For applying an absolute placement the entity `IfcLocalPlacement` is used, but its attribute `PlacementRelTo` is not supplied with any data and stays empty. In case of relative placement the entity `IfcLocalPlacement` is also applied, but the attribute `PlacementRelTo` links to another `IfcObjectPlacement` entity of the depending object (cf. [Figure 13](#)). (bSI - IFC2x3 Documentation, 2020; Borrmann et al., 2021a)

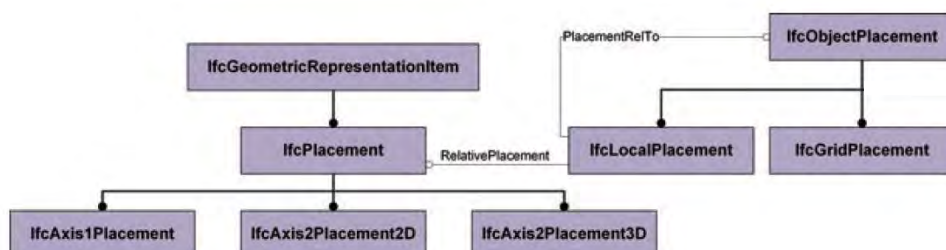


Figure 13: Overview of the Hierarchy of Object Placement (based on Borrmann et al., 2021a, but with neglecting `IfcLinearPlacement`)

Transforming the local coordinate system to the global one in 3-dimensional space is defined by `IfcAxis2Placement3D` and explained in [Figure 14](#). The attribute location is given as a Cartesian point and the orientation of the coordinate system is determined by the attributes of `Axis` and `RefDirection` (implemented as entity `IfcDirection`). (Borrmann et al., 2021a)

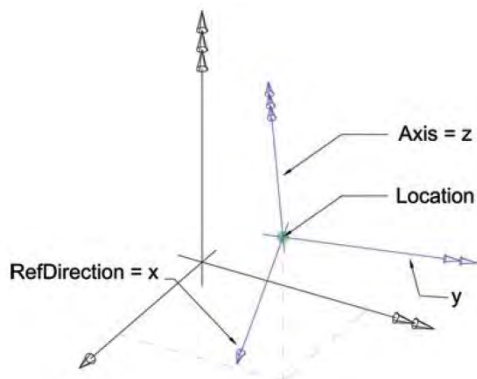


Figure 14: Principle of `IfcAxis2Placement3D` (Borrmann et al., 2021a)

Geometric Representation

The semantic and geometric description of an object is separated strictly within the IFC schema. In the first stage, an object is defined through its semantic description. Through this, it gets an identity within the model. In the next stage, it can be assigned to one or more geometric representations. (Borrmann et al., 2021a)

The IFC schema provides the definitions for many different types of geometric representation. They can be subdivided in two main groups:

- *explicit representations that describe the geometry of volume objects by their surface*
- *implicit representations (also called procedural descriptions) that describe the construction history, i.e. the operations applied to create the geometry*

(Michel Rives et al., 2020)

Both types have their specific advantages and disadvantages dependent on the particular use case. Which representation is beneficial to apply in a specific situation is explained in the following section.

The explicit representation is often named as Boundary Representation or BRep and is the most flexible method to describe 3D-objects. (Borrmann et al., 2021a) Within this method, a body is defined by the following hierarchy, where each element of the hierarchy is described by the definition of elements of the next smaller level.



Figure 15: Hierarchy within boundary representation

As this option does not describe the creation process of a geometric representation, it is not modifiable after transferring it into an IFC file. Explicit geometries only represent the interpreted results of the whole modeling process. They are not editable after the export process. If the geometric representation has to be edited in a downstream task, explicit representations are not the most suitable solution for this use case. (Michel Rives et al., 2020; Borrmann et al., 2021a)

To describe the construction procedure of an implicit geometry different methods can be applied. In the Construction Solid Geometry (CSG) method primitive bodies as cubes, cylinders or pyramids are taken as basis to apply Boolean operators on them. A tree structure describes the construction process of the resulting geometry precisely. The usage of only primitives limits the geometry. Many software therefore support the option of including self-defined 3D bodies as operands in the process, which greatly expands the variety of 3D bodies. (Borrmann et al., 2021a)

Another method builds the extrusion or rotation method, where a 2D-geometry is led along a 3D path to construct a 3D body. The basic construction processes are explained in [Figure 16](#).

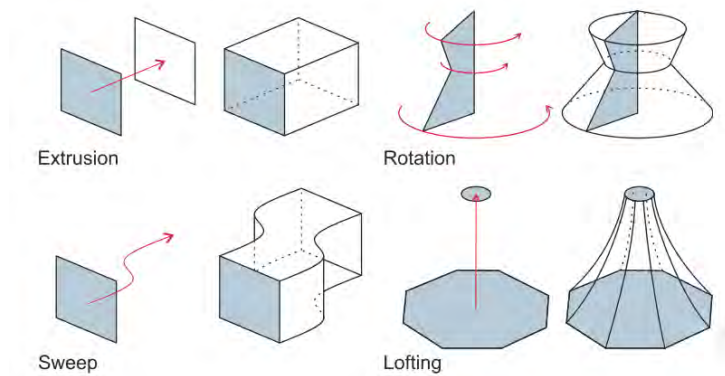


Figure 16: Rotation and extrusion methods (Borrmann et al., 2021a)

Implicit representations use significantly less memory, but the software on the receiving side has to handle all the described operations in exactly the same way as in the initial software. This leads to enormous difficulties in the area of software interoperability.

BIM-systems often use both representation option for one geometry at the same time. So, implicit and explicit representation are usually part of the data exchange process. The steps of the modeling process are offered as basis for geometry reconstruction. Additionally at the same time, the implicit geometry is converted into an explicit geometry for visualisation reasons within the software. (Borrmann et al., 2021a)

3.1.3 Development Process of the Schema

Various approaches to apply the IFC2x3 schema on alignment-based projects have been carried out. These attempts mainly focus on roads and rail projects. (Kwon et al., 2020) As identified in the literature, the standard of IFC2x3 fails to satisfy the requirements to model infrastructure projects. (S. A. Biancardo et al., 2021; Pasetto et al., 2020) This is why in 2018, bSI formed several project teams designated to extend the IFC schema towards supporting infrastructure assets. In detail, the teams are responsible for developing the extension of IFC Common Schema, IFC Bridge, IFC Road, IFC Ports & Waterways and IFC Rail. An overview is given in [Figure 17](#). One of the main tasks of is to include a method for linear referencing to support alignment structures within the digital models. (Stefan Jaud et al., 2020)

To extend the schema, bSI developed an internationally standardised process comprising three steps, which each schema release goes through. Within the first step of initiation, the needs of the industry are analysed and the bSI Standards Committee suggests a project proposal that follows clearly defined criteria. Within the second

phase of development, domain experts determine the domain requirements. These requirements are formulated in the IDM and implemented in a conceptual model by technical experts. The components of this conceptual model are mapped to the IFC schema and transmitted to the MVDs. The last step includes the approval of the extension by the Standard Committee. If it gains the candidate standard status it is implemented by software vendors and thus tested in real-world processes. The status of a final standard from the Standard Committee is given, if its application is checked for sufficient reliability and validity. (Stefan Jaud et al., 2020)

As shown in [Figure 6](#), the development process from IFC2x3 to the current candidate version of IFC4x3 passed several steps. From IFC2x3 to IFC4, new BIM workflows were added, such as the exchange of 4D and 5D data are enabled, property definitions can be connected to the bSDD, and new features in geometry and parametric. (bSI - IFC release notes)

Table 2: Overview Development of IFC 4 (Ait-Lamallam et al., 2021)

IFC Standard	Development Period	IFC Version	Status
IFCAlignment	2013–2017	IFC 4.1	IFC official standard
IFCBridge	2017–2019	IFC 4.2	Withdrawn
IFCInfra	2017–2021	IFC 4.3	IFC candidate standard

From the official release of IFC4 to IFC4x1, improvements in handling property sets and complex geometries, such as the tessellated geometry for the Reference View or the advanced boundary representation (Design Transfer View) within the model have been made. These changes were applied based on experiences from the pilot implementations. (bSI - IFC release notes) Furthermore, the first suggestion of including an alignment decomposed in horizontal and vertical alignment for infrastructure assets, including linear placement, was made. As a major reason, IFC4.1 was implemented to build the basis for further infrastructure domain extension. (bSI - IFC release notes)

IFC4.2 focused on an extension for bridges with their structural parts. The spatial structure is adapted to infrastructure assets. (bSI - IFC release notes) As this version was not efficiently working with the whole concept of structural elements in civil works, it was not further traced. (El-Amraoui-Farssi et al., 2022) In their railway pilot project

Ciccone et al. (2022) indicate limitations in semantics within IFC4x2, especially in the modeling of railway components.

IFC4x3 builds an overall solution for infrastructure assets and includes, besides the bridge extension, the results from the domain projects roads, rails and ports/waterways (Figure 17). The numerous changes applied within this release are analysed in detail in chapter 3.1.4. IFC4x3 is developed through different release candidates (RC). Within IFC4x3 RC1 the alignment definition was extended to include railway cant and enable span placements. Further adaptations were made in geometry, the spatial composition structure and definitions of product types for common domains. (bSI - IFC release notes) RC1 has been withdrawn due to weaknesses in newly implemented elements. The issues were identified, among other things, in redundancies of point and direction expressions, unclear orientation definitions of coordinate systems, and placement chaining. (Jaud et al., 2021) These points have been improved within seven months, and the new release candidate of IFC4x3 RC2 has been published. (El-Amraoui-Farssi et al., 2022) Changes from RC2 to RC3 are the extension of TypeEnums within the IfcRoad and IfcRail and adaptations in the geometric resources. From RC3 to the current version of IFC4x3 RC4, the infrastructure assets are moved to their own domains. In addition, property sets to describe the road and port/waterways domains are added. (bSI - IFC4x3 Documentation (Draft), 2021) Now, the current release candidate is IFC4x3 RC4 (bSI - Development Repository).

The future release of IFC4x4 will support functionality for tunnels as well (bSI - IFC specification Database).

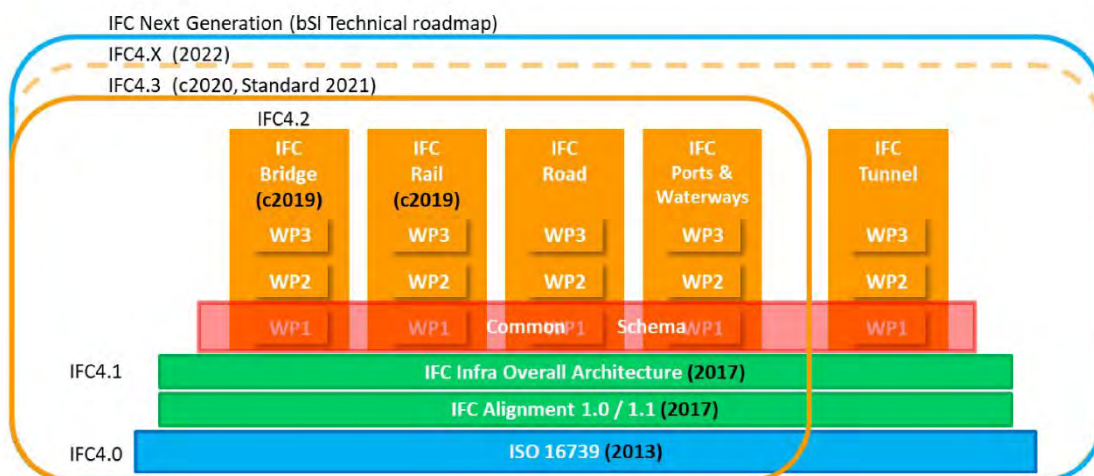


Figure 17: Overview IFC Development (Stefan Jaud et al., 2020)

As discussed here, the development process of the IFC schema is a continuous ongoing process. Since the time point of the application of adaptations is not relevant for the scope of this work, the chronological and versions-related development will be neglected within the further analysis. The following chapter will only imply the present differences between IFC2x3 and IFC4x3 and will not explain which entity has been added in exactly which step in between. The analysis is based on the IFC4x3 documentation by buildingSMART international.

3.1.4 Composition Differences in IFC 4x3 and IFC 2x3

Kernel

In the IFC kernel basic adaptations have been made over the development process of the schema. The amount of entities of the `IfcKernel` increased from 37 to 49. The most relevant changes will be analysed in the following section.

First of all, the ownership and change information have been made optional and are not a compulsory information anymore by defining an instance that inherits from `IfcRoot`.

The abstract supertype of `IfcObjectDefinition`, which builds “the generalization of any semantically treated thing or process, either being a type or an occurrences” (bSI - IFC4x3 Documentation, 2022), is extended in the following way: `IfcTypeObject` specifies “information about a type, being common to all occurrences of this type” (bSI - IFC4x3 Documentation, 2022). In IFC2x3, `IfcTypeObject` has one subtype `IfcTypeProduct`. For IFC 4x3 the subtypes are extended by `IfcTypeProcess` and `IfcTypeResource`.

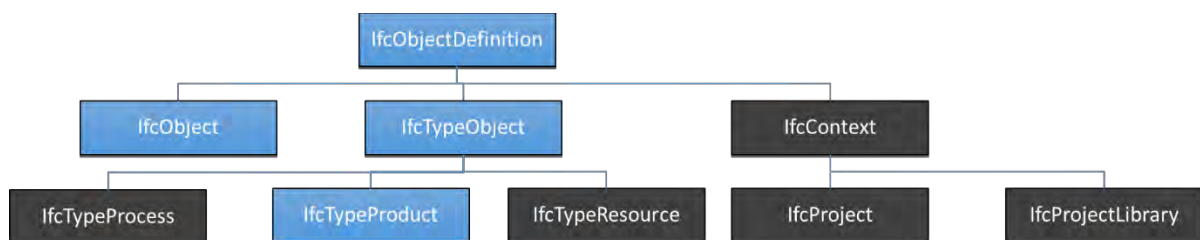


Figure 18: New structure sub-types of `IfcObjectDefinition` (black marking: new Entities in IFC4x3)

Instances of `IfcObject` are pieces of information, which can be related to other independent pieces of information by classes of relationships. In IFC2x3 three main kinds of relationships are used to connect information pieces with each other. In IFC4x3 the types of relationship are extended up to four types by splitting the decomposition relationship to un-ordered aggregation (`IfcRelAggregates`) and ordered nesting relationships (`IfcRelNests`), which gives `IfcRelNests` a new purpose to be used. In addition, `IfcRelNests` attribute of `RelatedObjects` (successor occurrence) is changed to be a list, which defines the order of the nested objects based on their position in the list. (bSI - IFC4x3 Documentation, 2022) `IfcRelNests` is applied, for instance, to attach the vertical or horizontal alignment segments in the correct order to the corresponding alignment structure (further explained in the “Resource Layer” section).

Additionally, in IFC4x3 the subtype `IfcContext` is added (c.f. [Figure 18](#)), that specifies the general context of a specific project in objects, type objects, property sets and properties. Project-specific product libraries can be determined in `IfcProjectLibrary`. Context information of the project can be stored in the entity `IfcProject` and assigned to the concerning entities with help of the newly added relationship `IfcRelDeclares`. (bSI - IFC4x3 Documentation, 2022) These new definitions delivers an improved basis for implementing semantics in the model.

As the IFC4x3 schema shifted `IfcProject` to the subtypes of `IfcContext` the new schema provides six subtypes of `IfcObject` and not seven as in IFC2x3.

In IFC4x3 `IfcRelDeclares` is added as a subtype to `IfcRelationship` (extension of [Table 1](#)). As explained before, this relationship is used to connect objects or properties with the subtypes of `IfcContext` (`IfcProject` or `IfcProjectLibrary`). (bSI - IFC4x3 Documentation, 2022)

In addition, some changes from IFC2x3 to IFC4x3 are implemented in the field of property management. An overview is given in [Figure 19](#).

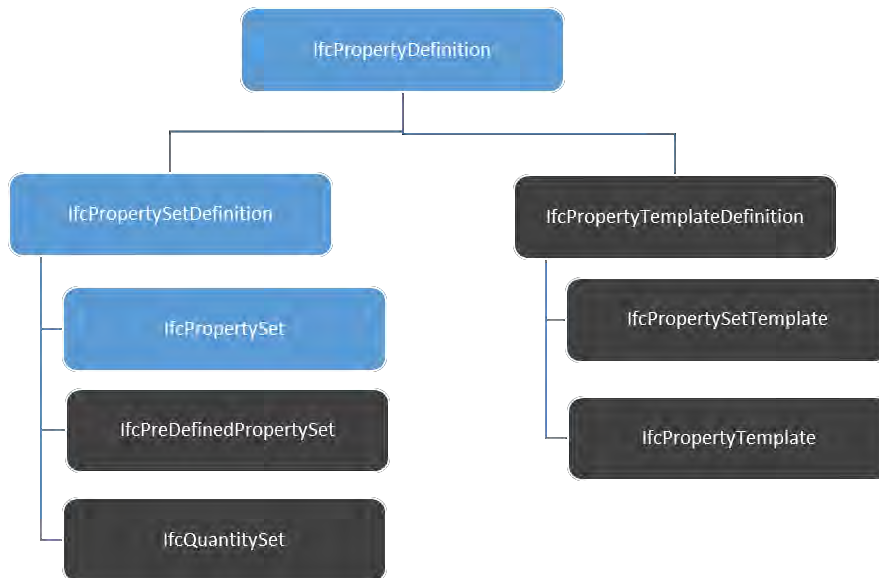


Figure 19: Overview property definition in the schema (black background: new in IFC4x3)

IfcPropertySet builds a container that holds properties in a tree structure. If the property sets are so called pre-defined or statically sets with a fixed list of attributes (known from schema IFC2x3) they are assigned to the entity IfcPreDefinedPropertySet.

Dynamically extensible property sets are contained in the tree structure of IfcPropertySetTemplate. One property set template may exist out of several property templates. IfcPropertyTemplates are defined by their name and data type (maybe including the unit) of the property. Property templates do not specify the values. The usage of these new features are explained in [Figure 20](#). Instances of IfcPropertyTemplateDefinitions are related to the context by the inverse attribute HasContext. Through extending the schema by the templates it is possible to assign every occurrence of a specific object the same properties. For instance, all walls within a project could have exactly the same template for semantical description. At the same time, the flexibility in property assignment is not limited and a user-defined selection of properties can be implemented. (bSI - IFC4x3 Documentation, 2022; Borrmann et al., 2021a)

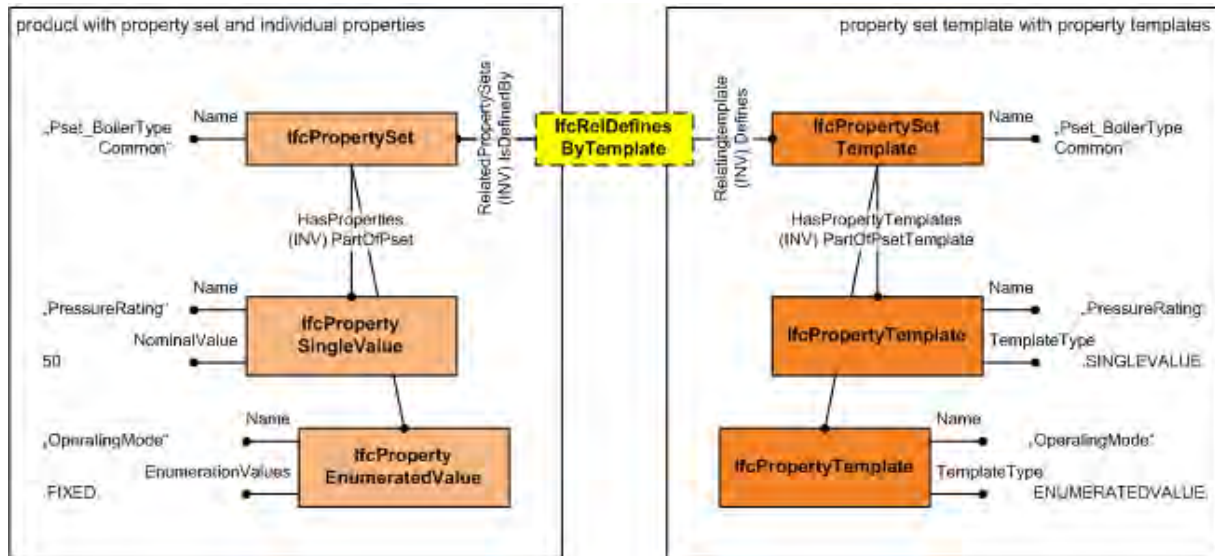


Figure 20: Application of pre-defined property sets (left) and property templates (right) (bSI - IFC4x3 Documentation, 2022)

So to sum it up, the extension of the schema regarding the property management provides the possibility to use predefined properties that refer to specific standards. In combination with extension of the `IfcProjectLibrary`, it extends the project-specific semantic information management, such as implementing content from the bSDD. `IfcPropertyTemplates` can also be used for information requirements management, as it specifies the type through which information should be implemented in a model. For instance, it could define the value to be a length, volume, list, table or enumeration. In practice, this method is not often used for information requirement. (Tomczak et al., 2022)

Control Extension

Due to the fact that the fourth entity `IfcTimeSeriesSchedule` of the control extension subschema of IFC2x3 is no longer provided, IFC4x3 exists out of three entities in the block of control extension. Time series can now be added to the new entity `IfcWorkCalendar`. With the implementation of the changes of IFC4x3, time-sensitive data can be tracked and adapted depending on the real-time situation. (bSI - IFC4x3 Documentation, 2022)

Process Extension

A lot of changes between IFC2x3 and IFC4x3 are applied in the process extension submodel. These changes are due to the topics in scheduling also related to the control extension. Before analysing the relations in detail, the basic changes in entities are determined.

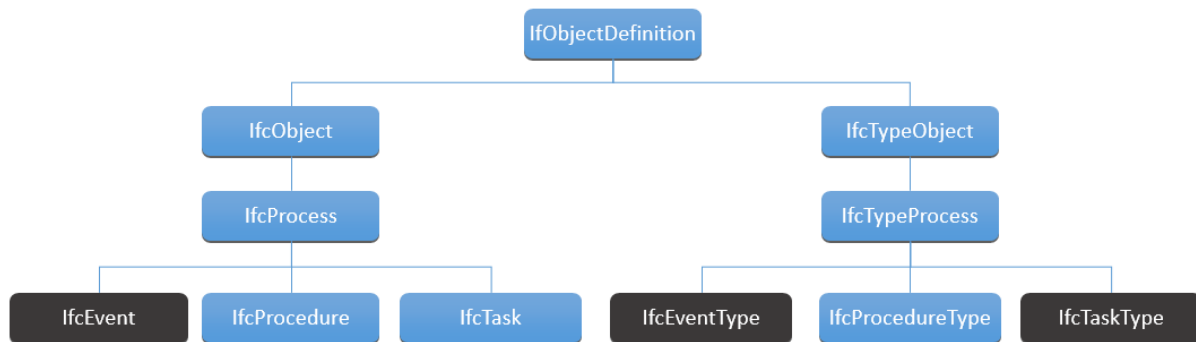


Figure 21: Changes applied within IfcProcess (black background: new in IFC4x3)

The amount of entities changed from seven to eleven. Among other changes, the subtypes of the entity IfcProcess are extended by the entity IfcEvent (c.f. [Figure 21](#)). An event is defined as “something that happens that triggers an action or response” (bSI - IFC4x3 Documentation, 2022). [Figure 22](#) explains the roles of events, tasks and procedures within an example situation. The event is no action itself, it is used as a point in the whole process to deliver a message that invokes a reaction.

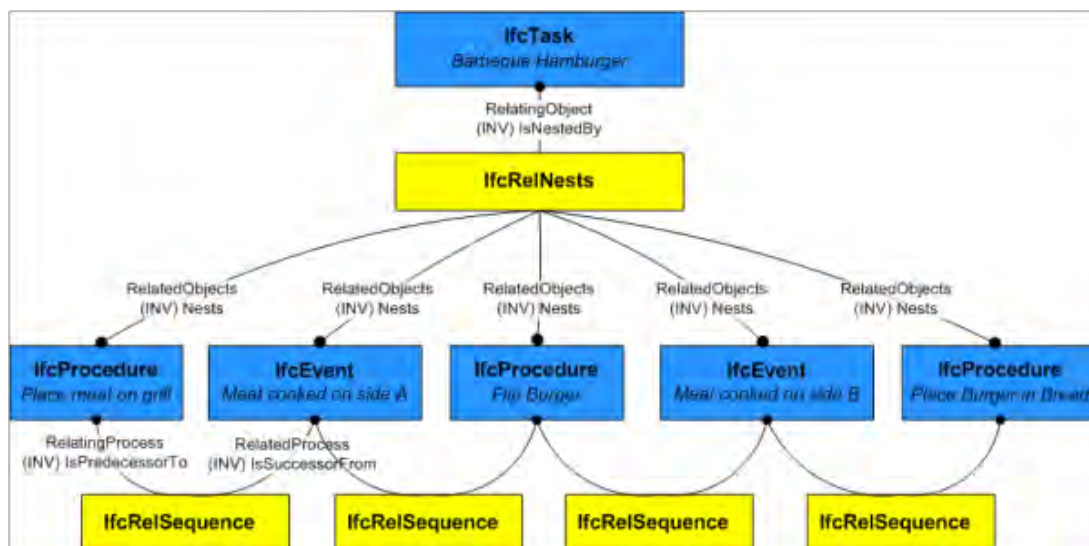


Figure 22: Explanation difference between IfcProcedure and IfcEvent (IFC 4x3) (bSI - IFC4x3 Documentation, 2022)

Furthermore, `IfcRelSequence` is newly located in the process extension schema. It is used as a 1-to-1 relationship to connect two processes to each other by making one to predecessor and one to successor (c.f. [Figure 22](#)). If, for instance, the completion of one process enables the start of many processes, many occurrences of `IfcRelSequence` would exist and start all at the same process to describe this condition, but the graph should stay non-cyclic in all situations. `IfcRelSequence` is extended within IFC4x3 by the attribute of `UserDefinedSequenceType`, which enables the specification of the relationship beyond the options of `START_START`, `START_FINISH`, `FINISH_START` or `FINISH_FINISH`. An example for this is given in [Figure 23](#), where in the second level task B.2 can only start, if task B.1 is finished. So if task B.1 would finish with a delay, it will also invoke a delay for task B.2. (bSI - IFC4x3 Documentation, 2022)

The IFC2x3 entity `IfcScheduleTimeControl`, which is implemented to define early/late start/finish times, float times, durations and actual times is no longer in usage. This information is now stored in the `TaskTime` attribute within the entity `IfcTask`. (bSI - IFC4x3 Documentation, 2022)

Within IFC2x3 the relationship `IfcRelAssignsTasks` is used to connect an `IfcTask` to an `IfcWorkControl`. This relationship class is now deleted, because within IFC4x3 a requirement is to have a summary task (“root of all tasks”) that is linked to `IfcWorkControl`. For this the relation class `IfcRelAssignsToControl` is used, where the `IfcTask` gets predecessor and the entity `IfcWorkControl` is successor. An example for the concept of the summary task as root entity for the smaller work packages can be seen in [Figure 23](#). If the root task is related to `IfcWorkControl`, it is not necessary to link every sub-task to an instance of the work control. (bSI - IFC4x3 Documentation, 2022)

Another example of the new usage of the entity `IfcRelNests` within IFC4x3 is given in the process scheduling context. Processes can be nested by this kind of relationship. Two examples are given within [Figure 23](#). The example in the 2nd level is further specified by the relation of `IfcRelSequence`.

A new entity within IFC4x3 builds the `IfcWorkCalendar`. As it is a sub-entity of `IfcControl`, it can be related by `IfcRelAssignsToControl` from `IfcTask` and `IfcResources` and determines working and non-working periods within a project. Tasks and resources are linked to one base calendar each, but the `IfcWorkCalendar` is for overall scheduling

and can therefore override parameters that are set in the base calendars. (bSI - IFC4x3 Documentation, 2022)

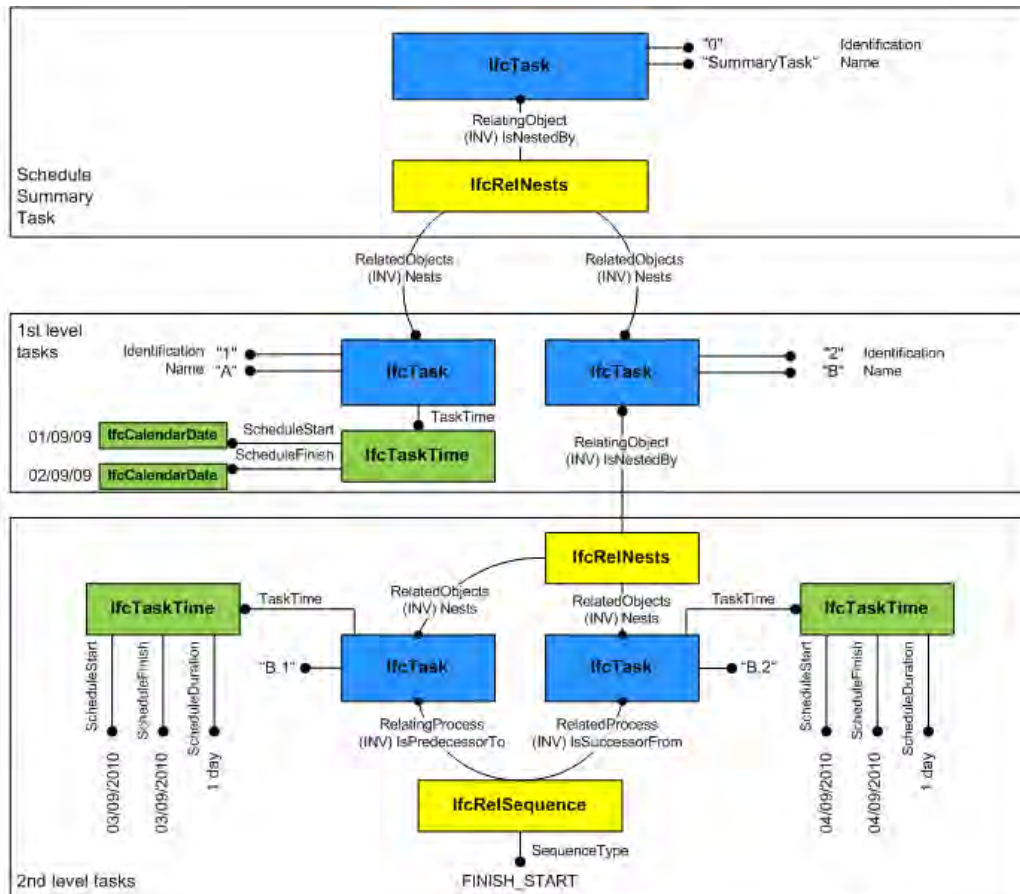


Figure 23: Example Process Management (bSI - IFC4x3 Documentation, 2022)

Up to earlier IFC releases, activities as move operations had been implemented through own entities as **IfcMove** which has now been removed. In IFC4x3 actors moving from one location to another location could be described as followed: Using **IfcRelAssignsToProcess**, where the predecessor points to the task of moving and the successor points to the location from where to move and with **IfcRelAssignsToProduct** (moving task as predecessor, location where to move as successor) the moving process could be modeled. (bSI - IFC4x3 Documentation, 2022)

Ait-Lamallam et al. (2021) state that adaptation made in the **IfcProcessExtension** are useful for the application in operation and maintenance management discipline (O&M).

Though, some limitations as advising tasks or procedures to actors (`IfcRelAssignsToActor`) seems to be not clearly defined. Additionally, the link between a process to an alignment for locating it, seem to be still not solved within IFC4x3_RC2.

Product Extension

In the product extension section, there are few structural changes only, but a lot of additions for describing the spatial structure of the model. The number of entities increased from 50 to 82 with the new release. Introducing some of these new entities is very important for the application of IFC in infrastructure project. (bSI - IFC4x3 Documentation, 2022)

One example for this is the entity `IfcAlignment`, which describes a curve in space. It inherits from `IfcLinearPositioningElement`. The following alignment entities inherit from the super type `IfcLinearElement`. `IfcAlignmentHorizontal` connects segments in the way end-to-start with each other, which are part of a projection on the x/y plane of a linear curve. `IfcAlignmentVertical` builds the height profile over the x/y plane projection of a linear curve. `IfcAlignmentCant` is an important extension to implement railway infrastructure. `IfcReferent` inherits from `IfcPositioningElement` and describes “a position at a particular offset along an alignment curve” (bSI - IFC4x3 Documentation, 2022). It is an important tool in infrastructure modeling and can be of different predefined types such as boundary (to describe that a boundary is crossing the alignment), intersection (to mark the position of an intersection) or station (for stationing data). (bSI - IFC4x3 Documentation, 2022)

`IfcBridge` is a newly added entity. It inherits from `IfcFacility` and gives the opportunity to implement a list of types or property sets to describe the bridge object further.

`IfcBuildingElement`, that describes “all elements that are primarily part of the construction of a built facility” (bSI - IFC4x3 Documentation, 2022) is renamed to `IfcBuiltElement`. `IfcExternalSpatialElement` is a new entity in IFC4x3 and can be used to define regions that are outside of the defined building site, as for instance the air space above the building site.

An overview of the new implemented `IfcFacilities` within the bSI extension projects is given in [Figure 17](#). The facilities implemented within IFC4x3 specify the projects in bridge, building, marine facility, railway or road. This specialisation will be extended in the future by, for instance, tunnel. The entity `IfcFacilityParts` is implemented to apply a

finer-grained spatial breakdown structure to the projects. (bSI - IFC4x3 Documentation, 2022)

To extent the schema for the requirements of infrastructure projects, the hierarchical composition structure of the project has been adapted. *Figure 24* shows the comparison to schema IFC2x3. IfcBridge, IfcBuilding, IfcMarineFacility, IfcRailway and IfcRoad are available as subtypes of IfcFacility.

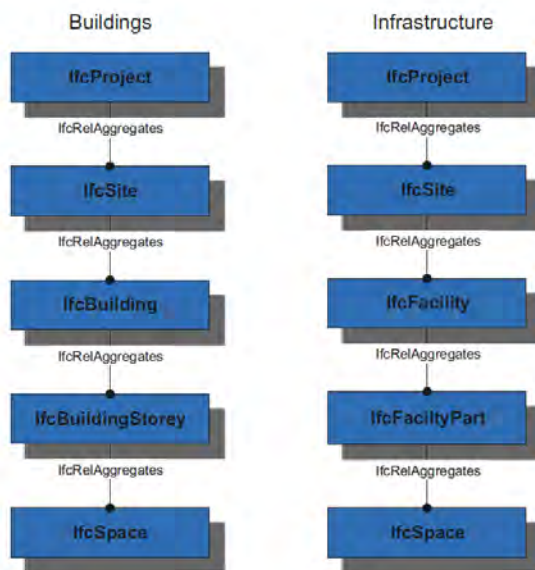


Figure 24: comparison of the hierarchic aggregation structure IFC2x3 (left) and IFC4x3 (right) (Borrmann et al., 2021a)

Some of the newly added relationship classes are IfcRelAdheresToElement, which links an element to one or many surfaces or IfcRelInterferesElement that is a 1-to-1 relationship to define that two elements interfere physically or logically.

IfcSpatialZone is a new entity in IFC4x3. It is a decomposition of the project by functional considerations while having its own shape representation.

IfcVehicle as subtype of IfcTransportationDevice or IfcVibrationDamper are examples for the accurate description that is possible within in the schema.

(bSI - IFC4x3 Documentation, 2022)

Shared/Interoperability Layer

The most relevant extension for infrastructure assets in the shared layer is the specialisation field of `IfcSharedInfrastructureElements` containing numerous new entities. This subschema is an important adaptation for the application of the schema in the field of infrastructure. It enables the implementation of fields, such as geotechnics with terrain modeling, earthworks structure, pavements, signs and signals.

Combining the IFC2x3 domain layer facilities management domain with the interoperability layer `IfcSharedMgmtElements` is another important adaptation on the way to the IFC4x3 schema. This extends `IfcSharedManagementElements` by the entities of `IfcPermit` and `IfcActionRequest`, which can now be inherited by all the domain schemas and is not limited to the domain of facility management any more. (bSI - IFC4x3 Documentation, 2022)

In addition, some new entities are added to the shared layer in other fields of specialisation. Since they are not particularly relevant for infrastructure facilities, they are not analysed within this work.

Domain Layer

As the domain layer supports the discipline-specific information delivery and actions, it increased through expansion of the schema to make it applicable over the whole industry. From IFC2x3 to IFC4x3 the number of domains increases from nine to eleven. As explained above, the facilities management domain gets annulled and moves to the shared layer. The domains of rail, road and ports/waterways are introduced in the new schema. The tunnel domain is in the development process and may be supplemented in the future. Highly relevant modifications of IFC4x3 in terms of infrastructure facilities, is the extension of domains. They are analysed in the following.

The three domains added for infrastructure project development use the `IfcSharedInfrastructureElements` schema as a basis. The `IfcPortsAndWaterwaysDomain` extends the shared layer by delivering a solution for cargo ports, passenger terminals, marinas, offshore construction base, canal networks, channel regulations and control and ship lock complexes. Aspects that are not supported within IFC4x3 are for example erosion protection, power generation, weirs and flood protection.

IfcRoadDomain supports inter alia highway, street, bicycle path, footpath, huge variety of junctions, road structure, sign elements, road pavement components, drainage system, underground facilities in the road body, ferry ports and airports. Out of scope are railway crossings, tramways and city scape or urban planning.

Most entities that are beneficial for the rail domain are defined in lower layers of the schema or in other domains. Topics and elements that are not covered by other parts of the schema and belong to the rail domain are different kind of rails, specific elements as e.g. sleepers and spatial structure types that are applied to break down railway projects. (bSI - IFC4x3 Documentation, 2022)

Existing domains are modified in IFC4x3 as following: The building control domain is extended by the occurrences of unitary control elements. Since the domain inherits from the core layer, it is linked to IfcPerformanceHistory and to the new definition IfcEvent. With this basis it can deliver, among other features, real-time control data or alarm event handling within the model. (bSI - IFC4x3 Documentation, 2022)

Through the basis of IfcProcessExtension and the IfcSharedMgmtElements schema the IfcConstructionMgmt domain is extended by aspects, such as resource productivity, resource allocation and levelling by time information, resource cost information and time-phased data to differentiate between scheduled work and actual work.

The electrical domain is largely extended from 19 entities to 50 entities. This leads to the support of communication systems. In addition, cabling for signal and control systems are part of the scope, which is important for signalling on e.g. a railway track.

The heating, ventilating and air conditioning (HVAC) domain is extended by 35 entities. Entities in the architecture domain are updated completely. IfcPlumbingFireProtectionDomain is nearly unmodified, so the scope has not been extended. (bSI - IFC4x3 Documentation, 2022)

Resource Layer

The number of resources decreases from 26 to 21. An overview is given in [Figure 25](#). The resource scheme of material property, presentation dimension, presentation, time series and profile property are not further supported in IFC4x3. In the following the changes in the resources most relevant for the infrastructure domains are investigated. Resources concerning 4D and 5D planning will be neglected.

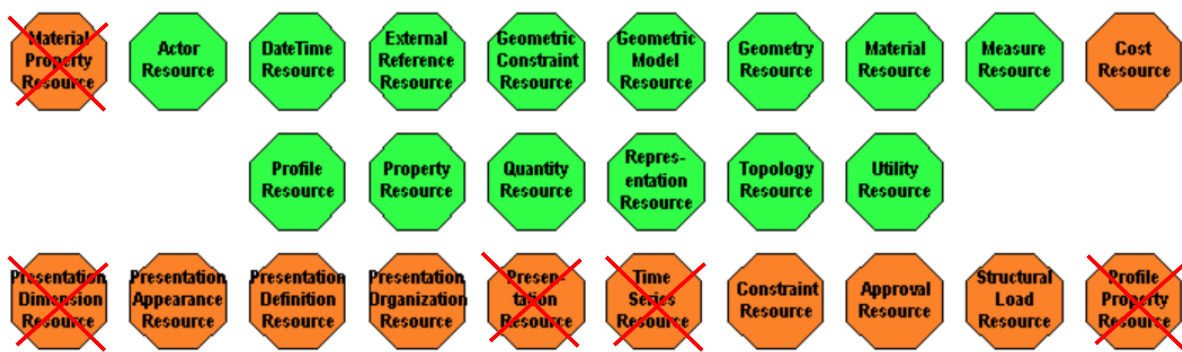


Figure 25: Overview resource layer (red cross: deprecated in IFC4x3) (bSI - IFC2x3 Documentation, 2020)

One of the primary changes in the resource layer are the geometric definitions. The schema of `IfcGeometryResources` extends from 44 entities to 76. In general it contains definitions for the geometric representations. Functionalities that are supported in IFC4x3 are the “definitions of parametric spline curves [and] surfaces and mapped items mapping source representations using transformation operators” (bSI - IFC4x3 Documentation, 2022). [Table 3](#) enumerates the new supplemented entities with IFC4x3.

Table 3: Overview new implemented entities in IFC4x3 `IfcGeometryResource`

<code>IfcAxis2PlacementLinear</code>	<code>IfcCosineSpiral</code>
<code>IfcBSplineCurveWithKnots</code>	<code>IfcCurveBoundedSurface</code>
<code>IfcBSplineSurface</code>	<code>IfcCurveSegment</code>
<code>IfcBSplineSurfaceWithKnots</code>	<code>IfcCylindricalSurface</code>
<code>IfcBSplineSurface</code>	<code>IfcDirectrixCurveSweptAreaSolid</code>
<code>IfcClothoid</code>	<code>IfcGradientCurve</code>
<code>IfcCompositeCurveOnSurface</code>	<code>IfcIndexedPolyCurve</code>
<code>IfcSineSpiral</code>	<code>IfcSphericalSurface</code>
<code>IfcThirdOrderPolynomialSpiral</code>	<code>IfcToroidalSurface</code>
<code>IfcIntersectionCurve</code>	<code>IfcRationalBSplineSurfaceWithKnots</code>
<code>IfcOffsetCurveByDistances</code>	<code>IfcReparametrisedCompositeCurveSegment</code>
<code>IfcOuterBoundaryCurve</code>	<code>IfcSeamCurve</code>
<code>IfcPcurve</code>	<code>IfcSecondOrderPolynomialSpiral</code>
<code>IfcPointByDistanceExpression</code>	<code>IfcSegment</code>
<code>IfcPolynomialCurve</code>	<code>IfcSegmentedReferenceCurve</code>
<code>IfcRationalBSplineCurveWithKnots</code>	<code>IfcSeventhOrderPolynomialSpiral</code>
<code>IfcSpiral</code>	<code>IfcSurfaceCurve</code>

IfcGeometricModelResource delivers the basis for geometric model representation.

The IFC4x3 schema has been extended by these methods:

Table 4: Extensions in IfcGeometricModelResource IFC4x3 (explicit: blue, implicit: yellow)

IfcAdvancedBrep	IfcIndexedPolygonalFace
IfcAdvancedBrepWithVoids	IfcIndexedPolygonalFaceWithVoids
IfcCartesianPointList	IfcTriangulatedIrregularNetwork
IfcCartesianPointList2D	IfcPolygonalFaceSet
IfcCartesianPointList3D	IfcRevolvedAreaSolidTapered
IfcDirectrixDerivedReferenceSweptAreaSolid	IfcSectionedSolid
IfcExtrudedAreaSolidTapered	IfcSectionedSolidHorizontal
IfcFixedReferenceSweptAreaSolid	IfcSectionedSurface
IfcSweptDiskSolidPolygonal	IfcTessellatedFaceSet
IfcTessellatedItem	IfcTriangulatedFaceSet

New options for explicit geometry representation are supported within IFC4x3, such as the IfcTessellatedFaceSet or the IfcTriangulatedFaceSet. The TriangulatedFaceSet represents surfaces by small triangles. It has to be mentioned, that this representation is an approximation of curved surfaces, where the accuracy is dependent on the chosen mesh refinement of the triangles. Even if the mesh is set to be very small, there will still be a deviation between the real geometry and the model representation. Additionally, the higher the number of triangles increases, the more memory the model demands. This method is often applied for use cases as visualisation or as description of a ground surface. (Michel Rives et al., 2020; Borrmann et al., 2021a)

The flexibility in extrusion and sweeping methods is improved through the implicit geometry extensions (Table 4). For instance, the IfcSectionedSolidHorizontal can be used for sweeping varying cross sections along an axis horizontally. (bSI - IFC4x3 Documentation, 2022)

The IfcGeometricConstraintResource schema contains the definition for the product's shape representation placement within the representation context of the model and definitions to describe the type of connectivity between two shapes.

One of the highly relevant modification in infrastructure assets in IFC4x3 are the extended specializations for object placement. As explained in chapter 3.1.2, for every

product that provides a shape representation one of the `IfcObjectPlacements` options local (absolute or relative) or grid placement is applied. In IFC4x3 these possibilities are supplemented by the third concept of `IfcLinearPlacement`. (bSI - IFC4x3 Documentation, 2022) The concept of positioning objects relative to a linear coordinationsystem is explained in [Figure 26](#).

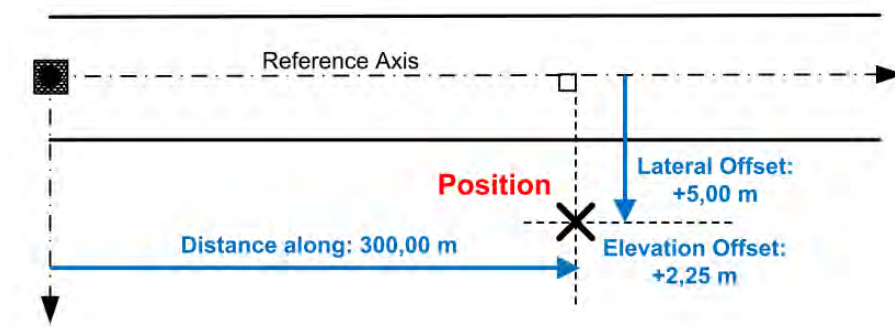


Figure 26: linear reference system (IFC Rail Project, 2019)

The attributes reference axis, distance along the axis, lateral offset and the elevation offset have to be available for linear placement of point objects. Stretched objects along an axis are implemented by their start and end point for distance along the axis, lateral offset (start/end) and elevation (start/end). (IFC Rail Project, 2019)

In IFC4x3, the attribute `PlacementRelTo` moved from the entity `IfcLocalPlacement` to its super type `IfcObjectPlacement`, which enables chaining of different types of placement. Except for the option linear placement being placed relative to another linear placement, which is excluded from the concept. (Jaud et al., 2021)

In addition, the orientation of a shape in an `IfcGridPlacement` (second attribute) can now also be taken directly from another grid intersection by explicitly specifying the direction.

The connection geometry between two shapes is also determined in this resource package. It can be either defined as geometric or topological representation items. Both options are extended by one description type within IFC4x3. These are the geometric option as solid connection and the topological option as closed shell connection defined in the new entity `IfcConnectionVolumeGeometry`. (bSI - IFC4x3 Documentation, 2022)

The basic definitions to implement alignment data are also part of the `IfcGeometric-ConstraintResource`. Common information about alignment placements are stored in the abstract entity `IfcAlignmentParameterSegment`. The start- and end tags at the segment are determined in this entity. The subtype `IfcAlignmentHorizontalSegment` deduces information about the horizontal alignment of the segment as the end point or directions at specific points. An element along a vertical alignment and cant segment is defined with `IfcAlignmentVerticalSegment` and `IfcAlignmentCant`. These data can be used to check the continuity over all segments. (bSI - IFC4x3 Documentation, 2022)

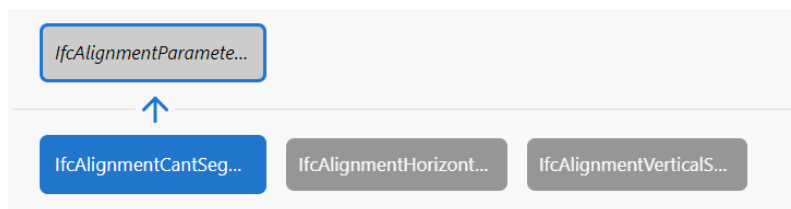


Figure 27: Overview alignment segment (bSI - IFC4x3 Documentation, 2022)

The resources added in the field of geometry and in the core data schema of `IfcProductExtension` build the fundamental concepts for integrating alignments in the schema. As the basic definitions of the alignment concept are spread over the schema definition, an overview is given in the following.

The term "alignment" describes several concepts that correlate, but must be treated separately.

1. Linear reference system for positioning
2. Ensuring kinematic conditions
3. Geometric construction of the track

(Andreas Pinzenöhler, 2022)

To meet all of these concepts and to avoid misunderstandings within the domain the term of IFC alignment is divided in the two main areas "business semantics" and "IFC geometry core".

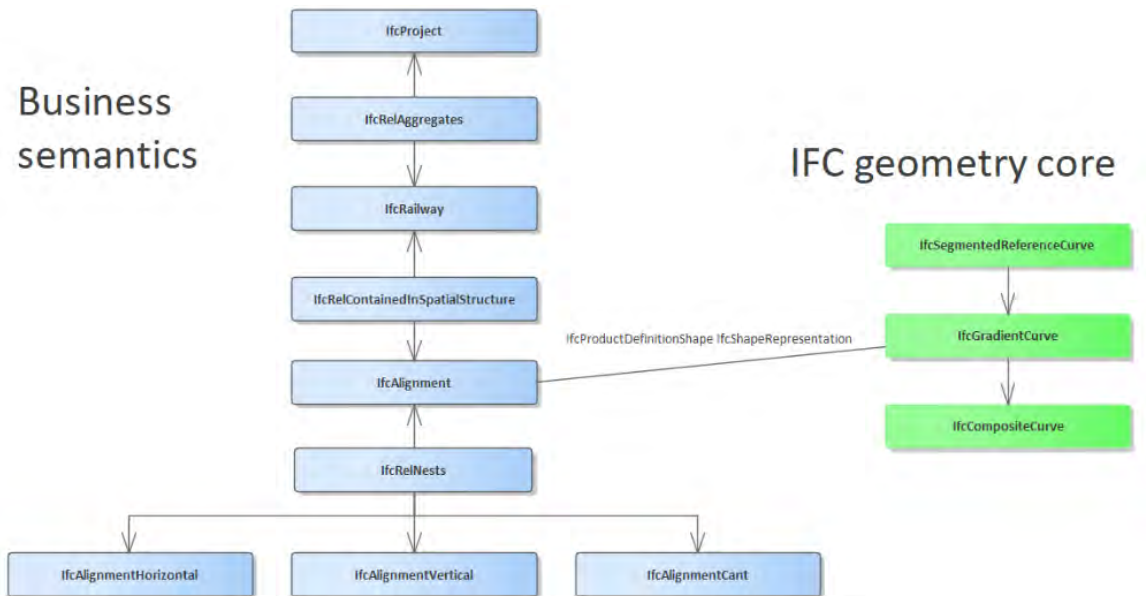


Figure 28: Business semantics (part of *IfcGeometricConstraintResource* and *IfcProductExtension*) and IFC geometry core (part of *IfcGeometryResource*) (Andreas Pinzenöhler, 2022)

The business semantics include the *IfcAlignment*, which is split up in the horizontal, vertical and cant alignment. These entities are further assembled by the segments (from *IfcGeometricConstraintResource*) described in [Figure 27](#). The geometry core describes the alignment based on the information delivered for each segment by the business semantics. (Andreas Pinzenöhler, 2022)

The elements of a track section are linked with each other in a chain. If changes are applied to one element (for instance small length adaptations) all following elements in the chain are dependent on the changes (IFC Rail Project, 2019). As described above this ordered composition relationship is implemented by *IfcRelNests*.

Concept Templates

Corresponding to the extension of the schema with IFC4x3, the MVDs have to be adapted. bSI defines the following MVDs for the usage of IFC4x3: Reference View, Alignment Based Reference view and the Design Transfer view. (bSI -MVD policy for IFC 4.x, 2021)

The Reference View is used inter alia for coordination planning, clash detection and quantity take-off.(Popgavrilova et al.) It is well developed and the compatibility with former versions is secured by fixed agreements, which cannot be modified. (bSI -MVD policy for IFC 4.x, 2021)

The Alignment Based Reference View was implemented as part of the IFC Bridge project. Since the alignment implementation changed from IFC4x2 to IFC4x3, adaptations for this MVD are required. (bSI -MVD policy for IFC 4.x, 2021)

The Design Transfer View is adapted within IFC4 towards advanced geometric and relational representation that targets an information transfer between different software. The version of DTV1.1 supports in the first step only one-way transfer of data. (bSi - MVD Database)

For the adaptations within the MVDs, the concept templates have to be modified or added to give a suitable basis for the MVDs of IFC4x3. (bSI - Development Repository)

Figure 29 visualises a newly introduced concept template by the example of parts of the concept “Alignment Layout” explaining the nested structure of the alignment segments:

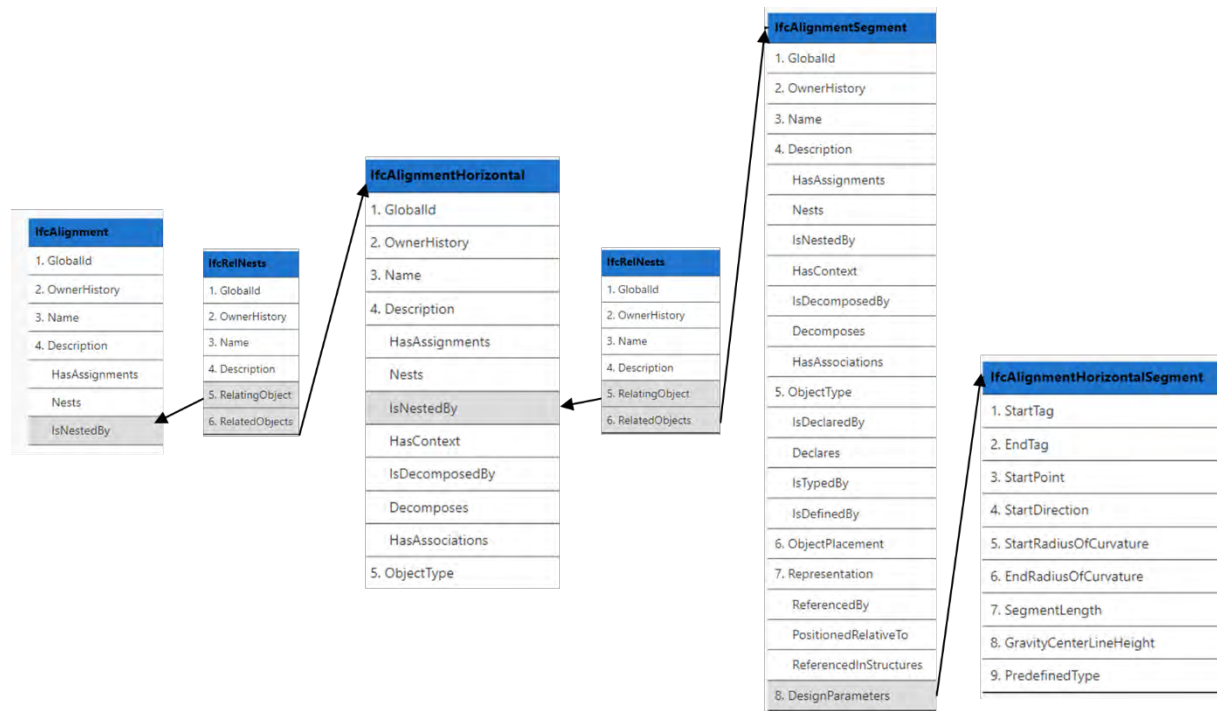


Figure 29: Example concept template of Alignment Layout (excerpt of horizontal alignment) (bSI - IFC4x3 Documentation, 2022)

3.2 Defining Evaluation Criteria Based on Use Cases

Comparing the documentaries of both IFC versions showed that fundamental changes have been introduced. Obviously, the adaptations in the domain layer concerning the addition of the infrastructure domains to the schema is an improvement towards infrastructure assets. However, the schema has been extended by much more entities. A summary is given below. To get an overview of the changes applied, the most relevant aspects are grouped by their fields of application.

The composition differences concerning the hierarchical structure of the model are the components of the Product Extension, such as adding the extension projects of the infrastructure assets and the spatial breakdown structure based on `IfcFacility` and `IfcFacilityPart`.

The adaptations within the kernel layer of `IfcContext`, `IfcProjectLibrary` and the property management all relate to the semantic implementation of the model.

The newly introduced features in the resource layer may influence the geometric representation of a model.

Great changes have been applied to the field of object positioning. This is influenced by the extension of the `IfcObjectPlacement` by its subtype linear placement and introducing `IfcAlignment` with all corresponding entities in the control extension and resource layer.

Changes in the Control Extension, such as adding `IfcWorkCalender`, including `IfcWorkControl` or adaptations within the resource layer, may build a reasonable basis for 4D planning. Since the planning process within the sample project in this case study does not include an IFC export of 4D data, the case study does not cover this field.

The remaining fields are hierarchy, semantics, geometric representation and object placement. In order to achieve tangible results within the case study, the evaluation criteria should cover these identified fields. This would ensure the highest range of differences within the outcomes.

As the entities elaborated above are instantiated in a model for a specific use, their attributes are accessed through concept templates (bSI - IFC4x3 Documentation, 2022). The concept templates determine the path through the schema and define which entities and attributes will be used to deliver information that is demanded

through the exchange requirements (c.f. chapter 2.3.4). The exchange requirements are defined in the IDM and describe the information needed to fulfil a use case. Considering these linkages, the concept templates, which apply the fields identified, deliver a sound basis to evaluate the models within this case study. Thus, the corresponding concept templates build the basis for the evaluation tool developed within this work. The tool delivers results in the fields of hierarchy, semantics, geometric representation and placement of an IFC model which can be used for further analysis.

4 Case Study: Ümraniye Ataşehir Göztepe Metro Line Project, Istanbul

4.1 Background Information

Istanbul is a fast growing city with an increase in population of more than 200.000 people every year, which builds up a growth rate of 1.4 %. In the year of 2022 the population is higher than 15.6 Mio. (macrotrends, 2022). To adapt to this increase in population and settled area, the public transportation system has to be steadily developed. *Figure 30* shows an overview of all stock metro lines marked in white and all metro lines in construction process right now, marked with red colour.



Figure 30: Overview Metro Lines Istanbul (Pelin Alpkökin IMM, 2019)

Since 2015, Istanbul Metropolitan Municipality (IMM) tenders its metro projects with BIM. It has been used over the whole process of main metro planning and construction. Within the past years, six newly built metro line projects have been carried out with BIM including 18 different stakeholders. (Akgüneş Ahmed, 2022) The following figure gives an overview of the ongoing projects *Figure 31*.

Projects	Project Delivery M.	Contract Type	Project Size	Client	Construction Manager	Contractor (GC)	Designer (S/C)	Start Date	Project Status	Award
Kabataş – Mecidiyeköy – Mahmutbey Metro Line	Design Build	Unit Price	18 km, 15 stations	IMM	EMAY Uluslararası Müh. Ve Müş. A. Ş	Alsım Alarko San. ve Tic. Tes. AŞ	Prota Mühendislik Proje ve Danışmanlık Hizmetleri A.Ş.	2015	Ongoing	AEC Excellence Awards 2017/Finalist/Infrastructure Category
Ataköy – İkitelli Metro Line	Design Build	Unit Price	13 km, 12 stations	IMM	EMAY Uluslararası Müh. Ve Müş. A. Ş	AGA Enerji Nak. Mad. İnş. San. ve Tic. AŞ	Prota Mühendislik Proje ve Danışmanlık Hizmetleri A.Ş.	2016	Ongoing	AEC Excellence Awards 2018/Finalist/Infrastructure Category
Dudullu-Bostancı Metro Line	Design Build	Unit Price	14.3 km, 13 stations	IMM	Arcadis – Tümaş JV	Şenbay – Kolin – Kalyon Dudullu – Bostancı Metro Construction Joint Venture	EMAY Uluslararası Müh. Ve Müş. A. Ş	2016	Ongoing	International Tunnelling and Underground Space Association 2017/Finalist
Göztepe – Ataşehir – Ümraniye Metro Line	Design Build	Unit Price	13 km, 11 stations	IMM	EMAY Uluslararası Müh. Ve Müş. A. Ş	Gülermak Ağır Sanayi İnşaat ve Taahhüt A.Ş. + Nuro İnşaat ve Ticaret A.Ş. JV	Yüksel Proje Uluslararası A.Ş.	2017	Ongoing	AEC Excellence Awards 2019/Finalist/Infrastructure Category
Çekmeköy – Sultanbeyli Metro Line	Design Build	Unit Price	17.8 km, 14 stations	IMM	Yüksel Proje Uluslararası A.Ş.	Doğuş İnş. ve Tic. A.Ş. + Özaltın İnş. Tic. ve San. A.Ş. + Yapı Merkezi İnş. ve San. A.Ş. JV	Tekfen Mühendislik A.Ş.	2017	Ongoing	-
Kaynarca – Pendik – Tuzla Metro Line	Design Build	Unit Price	14.2 km, 13 stations	IMM	-	Alsım Alarko San. Tes. Ve Tic. A.Ş. + Cengiz İnş. San. Ve Tic. A.Ş. JV	Prota Mühendislik Proje ve Danışmanlık Hizmetleri A.Ş.	2017	Ongoing	-

Figure 31: Overview ongoing IMM metro projects (Akgüneş Ahmed, 2022)

Even though these metro projects are the first BIM mandated projects in Turkey, there is rarely research work carried out to spread the experience taken from the ongoing project. Some examples are given in the following: Akgüneş Ahmed's (2022) research focuses on the implementation process and adoption of BIM in the metro projects of IMM. The study includes surveys and interviews with professionals involved in the process to ascertain the state of the art concerning characteristic features, challenges, barriers, benefits and lesson-learned of BIM implementation within the past years in case of the metro line projects. (Akgüneş Ahmed 2022) Aside this research, until now Akarcalı & Ergen (2020) investigated construction and lean interaction on the IMM Dudullu-Bostancı metro line project, Saniye Oktem et al. (2018) determined benefits and challenges of BIM in infrastructure projects in general and Alpkökin & Çelik (2020) research about the BIM implementation process in the Ataköy-İkitelli metro line project. There is a high potential for further dissemination of the experience gained within the past years of BIM implementation in metro projects. As stated by Akgüneş Ahmed (2022), it is highly relevant to define standards in the BIM process in Turkey with using this gained knowledge. The work of A. Akcamete et al. (2020), which had been introduced in chapter 2.3.3 within this thesis, addresses the lack of standards identified in Turkey by taking international sample EIRs as example to develop a template for the ongoing metro projects in Istanbul.

As most of the research papers focus on the BIM implementation in process management scale, none of the papers analyse the BIM models created at the level of the schematic structure of the models. As exposed in chapter 3.1.4, the development of the IFC schema is currently improved towards built assets in infrastructure projects. Especially for the tunnel domain, the IFC schema has not yet been extended and will not even be included in the IFC4x3 release. (bSI - IFC specification Database) Taking this knowledge into account, it may be highly beneficial to investigate the solutions applied in the metro projects in the context of implementing infrastructure facilities. The upcoming case study takes this approach as a basis to investigate the models at the scale of data modeling.

4.2 Project Process and Model Selection

The modeling process in the ÜAG project works as follow: The BIM models are composed of five main different discipline models including geotechnical, mechanical, structural, architectural and electrical disciplines. The Common Data Environment (CDE) within this project is built up by Autodesk's solution BIM360 and the global project document management system EDMS that is developed by ENKA systems as a hybrid system. (Akgüneş Ahmed, 2022) The models are updated every two weeks within the CDE by uploading the files as defined in the BIM Execution Plan (BEP) of the project. In this case, it means a handover of the models as IFC, Autodesk Revit and Autodesk Navisworks files, as required by the contractor. Corresponding DWG files should also be added. Since all participants involved in the process use the same modeling software (Revit, Navisworks), the process is currently not highly dependent on the IFC files. However, the delivery of the project is carried out including all related formats of Navisworks, Revit and IFC. These formats, also including IFC files, are required over the whole project process, starting from the project delivery of the schematic phase (Figure 32). Hence, improving the IFC exchange process to a reliable and loss-free information transfer within the projects is a long-term goal. The models are exported to the current standard release of IFC2x3 in the MVD Coordination View 2.0.

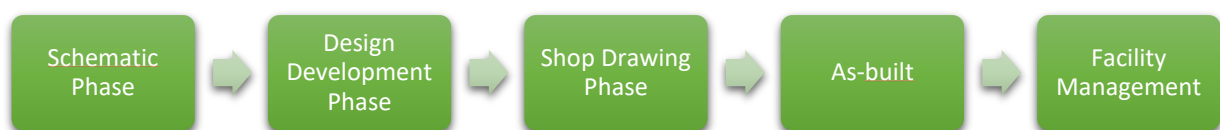


Figure 32: Flowchart of the project process

Even though IMM has other ongoing projects the Ümraniye-Ataşehir-Göztepe (ÜAG) metro line project is chosen for the case study, because its project progress is at further stage in the project life-cycle. Therefore the models are more developed than the other IMM projects. The ÜAG metro line project is at the construction drawing phase. An overview of the line is shown in [Figure 33](#).



Figure 33: Overview map of Metro Line Ümraniye-Ataşehir-Göztepe on the Asian side of Istanbul (Pelin Alpkökin IMM, 2019)

The models are all set on a common global coordinate system. In this project, it is the TRF 96 Turkey coordinate system. The coordination model of the project is separated in two types of partial models: 1) Station models and 2) line structures as tunnels. (Akgüneş Ahmed, 2022)

The study covers both of the model types to gain as much understanding of the model strategy as possible. Since in the research scope and planned time period it is not possible to investigate all of the models available in the project, the “Ataşehir” and

“Finans Merkezi” stations are selected, because they are further advanced in the project process. Accordingly, the tunnel model of the connecting section between these two stations is selected to be analysed as line structure model in this case study.

Since the models are analysed in small scale, the study focuses on a single discipline. To select a suitable discipline for the case study, following aspects are considered: The electrical, as well as the mechanical models contain no structural elements. The geotechnical model targets very specific use cases, which are not specifically relevant to the infrastructure domain. Therefore, these models are not suitable to cover a broad basis to investigate the capability of IFC. The architectural models of the stations contain detailed visualisations and fine-grained design, since the project planned delivery time requires the architectural models to be further developed than the other disciplines. However, the station models should be comparable to the tunnel model to have a consistent data basis for evaluation. As the study should focus on the potential of IFC in the transportation infrastructure, choosing the most suitable tunnel model is crucial. The linear aligned tunnel segments in the tunnel model, might be in the focus of infrastructure related investigations. Since the tunnels segments are part of the structural model, the study will focus on this discipline.

4.3 Analysis of the ÜAG Models

The following section investigates how information is generally represented in the IFC2x3 models of the ÜAG project. In detail, it will be elaborated, if the IFC2x3 schema builds a suitable format for representing and storing the models' infrastructure-related information and if IFC4x3 can provide an enhanced basis for the models to apply downstream tasks.

4.3.1 Technical Setup and Approach of the Study

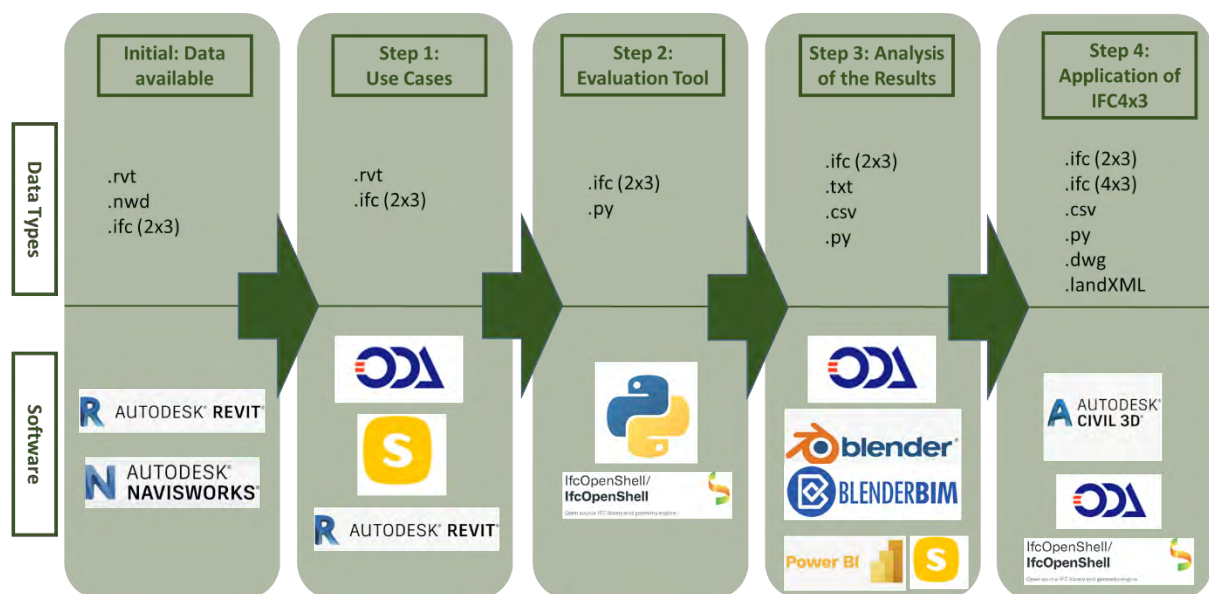


Figure 34: Visualisation of the Technical Setup

An overview about the technical setup is given in [Figure 34](#). Explanations to each software selection is given in the following.

Revit and Civil 3D are Autodesk's major software applications for BIM. Revit finds its application in the field of buildings and Civil 3D is a solution for infrastructure projects. (Autodesk, 2022 – Revit IFC Manual 2.0, 2022)

Revit is utilized, among others, by Architects, structural engineers, MEP engineers, builders and owners for the projects' design, documentation or visualisation tasks. (Autodesk Revit) The investigated models within this case study are mostly created in Revit. The native data type is RVT, so the initial models are available in this format.

Civil 3D is a tool for civil infrastructure professionals and participants involved in the design process of large scale infrastructure projects. (Autodesk Civil 3D, 2022) The Add-In "IFC4x3 Extension" enables the import and export processes in Civil 3D for the

latest version up to IFC4x3_RC4. It supports mapping of Civil 3D objects to IFC objects and types, as well as to bSI property sets. Additionally, it provides the basis to instantiate entities defined in IfcBridge, IfcRailway and IfcRoad. (Secerbegovic, 2022) In the scope of this case study, it is used for the IFC4x3 remodeling in chapter 0.

Autodesk Navisworks is a coordination software to review models and carry out clash detection (Autodesk Navisworks, 2022). Within this study, it is used as model viewer for the coordination model.

The ODA viewer, developed by Open Design Alliance, is a software application that provides viewing capabilities for IFC files. It is chosen because it supports IFC4x3_RC4 models and is applicable for clash detection (Opendesign Products, 2022). In addition, several settings can be adjusted for viewing the models. This includes the type of modeler of “Facet” or “Brep”, the accuracy and the type of model (e.g. axis, body or foot print representation). It is utilized for the use case of visualisation, to analyse the results of the tool visually and to check the IFC4x3 models exported from Civil 3D.

Additionally, Solibri Model Checker (SMC) is used for clash detection and quantity take off. It executes predefined rules for clash detection and is a beneficial alternative model viewer as it has a useful search function for model properties. (Solibri, 2022)

As both, SMC and the ODA viewer aim for visualization and model analysis based on interpreted BIM-models, a third tool has been added to the technical setup. It is developed within this work and aims to unveil modeling information based on a purely data level without any further interpretations or calculations. The basis of the evaluation tool builds the python open source library IfcOpenShell (IOS) (IfcOpenShell, 2022). This is a python library that supports the work with IFC files by a simple way to access and modify the entities. It uses the late binding approach. This means IOS is based on a predefined Standard Data Access Interface (SDAI), which is a programming interface that includes clear defined functions and methods to read and modify a STEP or an IfcXML file. (Amann et al., 2021) Accordingly, the entity definitions are accessed during program runtime. Unlike early binding approaches, where each IFC entity has to be implemented in a class in the applied programming language in advance. Therefore, there have to be predefined classes for each IFC schema release and in the case of applying changes, the corresponding classes have to be adjusted. As the late binding approach is based on strings and not on defined classes it is error-prone for syntax

errors. (Deian Stoitchkov et al., 2020) However, the IOS approach is chosen for this case study, because it is straightforward to apply it to the different IFC schema versions, which builds the core of this thesis.

Blender is a “free and open-source creation suite” (Blender, 2022). The BlenderBIM Add-on is a powerful tool to connect IfcOpenShell with an user-interface (Wiki.OSArch, 2022). It is used to visualize the outcomes of the evaluation tool in a particular case in the context of their placements or geometric representations.

PowerBI is a data visualisation tool that allows representing heterogeneous information on the basis of many different data types. Due to its ability to handle csv and json files, this software is chosen for the visual representation of the results extracted. (Microsoft - power BI, 2022)

Additionally, for the first overview of the delivered results, the python library matplotlib is used for direct visualisation within the scripts.

The scope of the case study is divided into four parts ([Figure 34](#)). The models are available as IFC2x3, Revit and Nawisworks files. Within the first part, the use cases visualisation, clash detection and quantity take off are applied to the models. For the visualisation, Solibri Model Checker and ODA viewer are used. The clash detection as well as the quantity take off are carried out by Solibri Model Checker. Measurements from Revit are considered as reference values in the quantity take off.

The application of the evaluation tool builds the second step. This is explained in detail in chapter 4.3.3.

The analysis of the evaluation tool outputs is part of the third step. With the help of visualisations in blenderBIM and supporting diagrams, the current approach using IFC2x3 for infrastructure models is analysed, and arising problems are identified.

In the fourth part, it will be discussed, whether the issues identified can be eliminated by the possibly future standard of IFC4x3. For this step, the tunnel model is partly remodeled in Autodesk Civil 3D, exported through the IFC Infra exporter (produces an IFC4x3) and re-analysed through the evaluation tool. The results are presented and discussed in chapter 0.

4.3.2 Applying Use Cases

Visualisation

When trying to visualise the tunnel IFC file with the IFC viewer, it can be seen that problems occur at the cross passages of the tunnel [Figure 35](#). Here, the geometry of the bonding elements is not completely included in the IFC model and leads to a gap in representation.²

[Table 5](#) gives a numbering for the intersections and an overview of how different viewers deal with the visualisation issue. As the tunnel section contains two main tubes and four cross passages connecting them, there are 8 intersections. The results show, that the problem occurs commonly at 6 intersections, but it does not occur in the original Revit file. This leads to the interpretation, that it is related to a Revit export problem concerning the geometric representation.

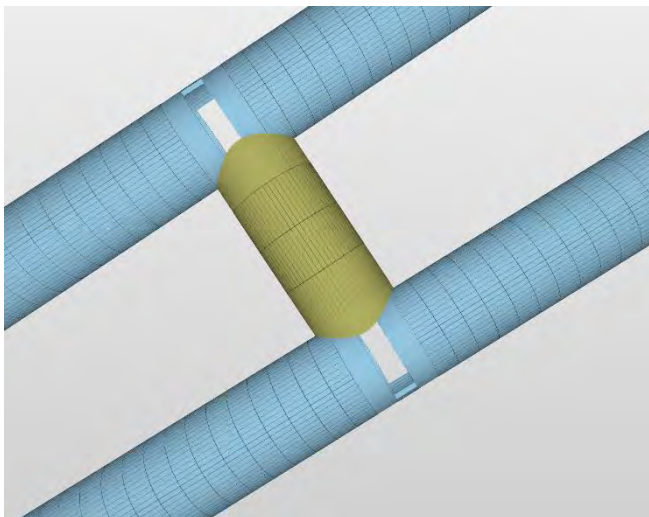


Figure 35: Gaps at tunnel cross passages in Solibri viewer

Table 5: Investigation of visualisation error in different software applications (1: gap occurs, 0: no gap in this intersection)

Intersection:	1	2	3	4	5	6	7	8
Navisworks (nwd)	1	0	1	0	1	1	1	1
Revit (rvt)	0	0	0	0	0	0	0	0
Revit (ifc)	1	0	1	0	1	1	1	1
ODA (ifc) (Brep)	1	0	1	0	1	1	1	1
ODA (ifc) (Facet)	1	0	1	0	1	1	1	1
Solibri (ifc)	1	0	1	0	1	1	1	1

² The use case of visualisation is investigated on the basis of the advanced tunnel model, which was handed over on the 06.10.2022

Clash Detection and Model Checking

As the design process in the ÜAG project is currently not dependent on IFC models since it is Revit and Navisworks based, Solibri model checker detects problems. Within this case study, only the problems relevant to the infrastructure extensions of the IFC schema will be analysed. Clashes or issues which are part of conventional high-raised building planning will be disregarded. An overview of the investigated clashes is shown in [Table 6](#) and further explained in the following sections. As the Finans Merkezi Station model contains infrastructure related components, this model is selected as station model in the model checking.

Table 6: Overview Model Checking

Model	Entity Type A	Entity Type B	No. Clashes	Visualisation
Station Model	IfcSlab (track superstructure)	IfcBuildingElementProxy (switch)	1	Figure 36
	IfcSlab (floor slab)	IfcBuildingElementProxy (tunnel wall)	46	Figure 37
Tunnel Model	IfcBeam (tunnel segment)	IfcBeam (tunnel tops or tunnel bottoms)	18	Figure 38
	IfcBeam (tunnel segment)	no element assigned above and on top of beam element	435	

Since the superstructure is implemented as an IfcSlab and the switch as an IfcBuildingElementProxy the model checker software assumes this being a problem if the switch overlaps with the superstructure. Obviously, switches have to interfere with the superstructure, but as these semantics are not defined in the model, SMC detects this case being an error.

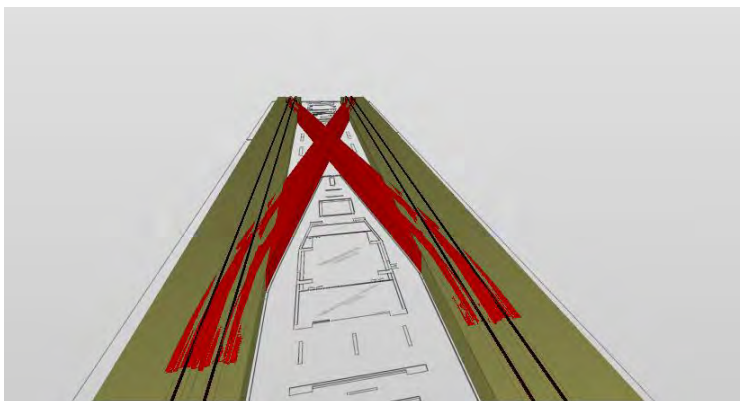


Figure 36: Conflict between IfcSlab and IfcBuildingEmelentProxy as switch

The floor slab of the access tunnel at the Finans Merkezi station is implemented as `IfcSlab`. The tunnel walls are implemented as `IfcBuildingElementProxy` entities. These two element types are defined on different levels and therefore different `IfcBuildingStoreys`. The inconsistency detected is an overlap of elements, which are part of different spatial containers. An improvement could be to define the access tunnel in a separate composited structure, decomposed by the floor slabs and the walls, in a similar way like the stair being decomposed by stairflights and slabs. The structure would then be part of a common spatial container.

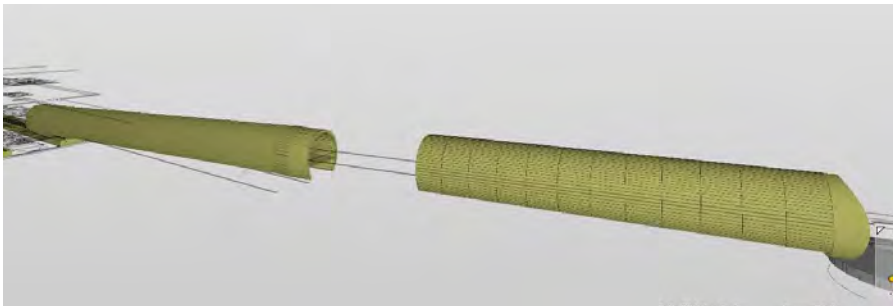


Figure 37: Walls and floor on different levels

The structural tunnel model checking investigates that the intersections of the cross passages with the main tunnel structure lead to errors. All of the four cross passages include elements that are marked with the problem of beams overlapping.

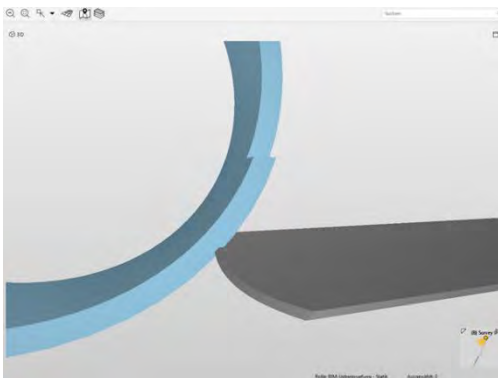


Figure 38: Overlaps of the tunnel segments at intersections

The second problem detected in the tunnel model is a structural problem. The tunnel segments are assigned to be `IfcBeam` entities. Since the beams are defined in a structural point of view of having one segment below and one segment on top, Solibri expects the beams to interfere with elements above and below. Since this is not the case within the tunnel model, 435 problems occur.

Additionally, the stationing labels of the tunnel model are assigned to be `IfcBuildingElementProxy`. Therefore, these elements are also part of the structural checking in Solibri and cause errors in the process.

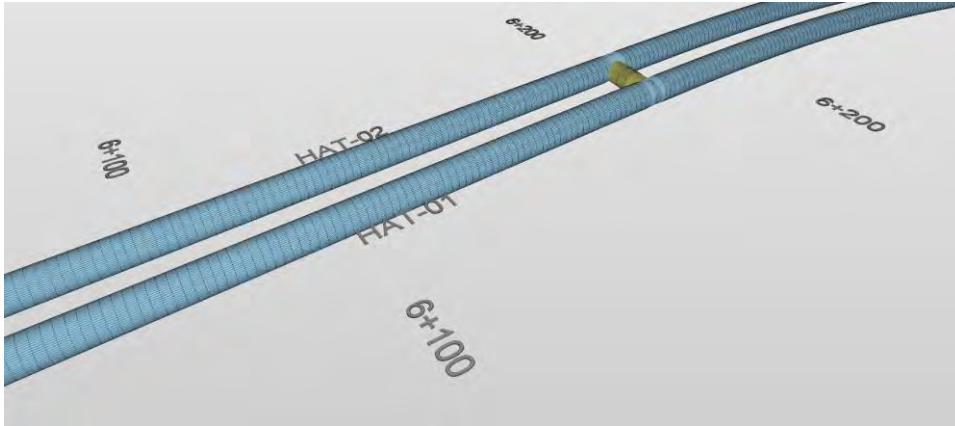


Figure 39: Labelling included in the IFC model

To sum it up, problems are detected within the model checking process. Some of these clashes should be solved, and some arise due to the lack of suitable IFC classes. It is difficult to assign the clashes identified to different levels of relevance. This could be improved by using more specific property sets. For example, by a clear definition through property sets of tunnel segments being assigned to `IfcBeam`, a new rule could be set to disregard the problems related to missing contacts of these elements. If the switch, which is located within the superstructure of the rail were clearly described by property sets, an exception rule could be implemented for the conflict.

Quantity Take Off

The following section will determine whether the quantity take-off based on the IFC2x3 output is consistent. The Solibri output is based on the measurements taken from Solibri directly out of the model and not based on the quantity sets assigned to the elements.

The Atasehir model was selected to carry out the Quantity Take Off regarding the station models. It includes well-structured lists of quantities within the Revit file, which enables a comparison between the Solibri output and the original model. The absolute numbers of the comparison of sample object groups are represented in [Table 7](#).

Table 7: Comparison QTO Station Model

[m ³]	Solibri	Revit
Total volume of beams (C30):	280.76	281.61
Total volume of concrete structures (C30):	32579.84	31334.57
Total volume of walls:	11378.64	11294.22

All in all, the IFC file based on Solibri quantities is close to the quantity lists in Revit. Looking at this small example, the Quantity Take Off for the station models seems to work in a reasonable way.

The quantity take off of the tunnel counts 1328 beam elements of different lengths. The total length of all beam segments is 2174,237 m. Since the length of the tunnel section is about 1100 m, the total length of all tunnel segments should be slightly higher (2200 m).

Concerning the Solibri take off 11037 m³ of concrete C40 are reported for the TBM segments. Compared to the present quantities in Revit the volume of the needed concrete C40 is 11353 m³. The difference of about 300 m³ could be related to the following point:

Inconsistencies in the length of some tunnel segments are exposed. As can be seen in [Figure 40](#), the segments at the cross passages are unequal to the length of Revit segments. For instance, segment 2210976 has a length of about 1.50 meters in the Revit model. The output of the Solibri model checker assigns it to be zero. Also, the segments assigned in the IFC model to have a length of 6.30 meters have lengths of 1.50 and 4.50 meters in the original model.

Kompo	Name	Fläche	Länge	Boden Fläche	Höhe	Volum	Zahl	Farbe
1228	Balken YP-C-M3-CTN-TBM:C40_TBM:2210962		6,3	10,1		8,05	1	
1229	Balken YP-C-M3-CTN-TBM:C40_TBM:2210976		0	0		0	1	
1230	Balken YP-C-M3-CTN-TBM:C40_TBM:2210990		6,3	10,08		8,22	1	
1231	Balken YP-C-M3-CTN-TBM:C40_TBM:2211004		1,49	10,11		8,41	1	

Figure 40: Problem of different lengths between the quantity take off based on ifc file and the original Revit file (tunnel model)

To sum it up, the quantity take off of the station model was reasonable. The IFC-based quantity take off of the tunnel model contains problems.

4.3.3 Introducing the Evaluation Tool

To gain a deeper understanding of the structure and data of the models, an evaluation tool was developed. The evaluation tool extracts raw data packages from the model. In detail, it accesses the data directly, before it is interpreted and visualised by software application. The delivered data bundles give an overview of aspects, such as the selected subtypes of IfcElement, property sets, geometric representations and hierarchy. This establishes an objective basis for analysing and evaluating the models in terms of their capability to serve the information requirements for downstream functions.

As explained in chapter 2.3.4, the concept templates are used to define how the IFC schema should be applied in particular scenarios. The evaluation tool is based on the idea of concept templates. It is not applying the templates through MVDs, as other software solutions. It rather shows several data sets, which are picked by each concept template. So it gives the ability to check the data sets selected by concept templates

in their raw version in a more convenient and structured way than in the IFC STEP file view. .

The evaluation tool has been implemented as a console application. To run the tool, the user has to enter several arguments. As a positional argument, the tool needs information about the directory where the IFC files are located (*Table 8* [-p]). This is a string input, so the file path has to be entered in quotation marks. The tool can handle multiple files at once. Therefore, the scripts will be applied to all IFC files stored in that folder directly. As second input parameter, the user has to enter a list of digits to specify the selection from 10 possible extraction routines to run for evaluation (*Table 8* [-1] to [-10]). The tool creates a new “IFC_EV_TOOL_results”-folder within the directory entered. This folder contains subfolders named after each IFC file. The output files for the evaluation steps selected in advance can be found in these folders after the tool has been executed successfully.

An overview of all optional extraction routines (each based on a single script) included within the tool is listed in *Table 8*. The data extraction methods are divided into three evaluation fields (Structure and Hierarchy, Placement, Geometry), and each of the scripts is based on a concept template defined in the IFC4x3 documentation of bSI (exceptional script 4).

Table 8: Overview within the Evaluation Tool (required argument: grey, optional arguments: orange)

	Call- ing	Description	Concept Template
	[-p]	Enter file path to the folder of the IFC file(s)	-
Structure and Hierarchy	[-1]	Hierarchy (Combining Ev2 and Ev3)	Element Decomposition, Spatial Decomposition, Spatial Structure
	[-2]	Composition Structure of Project	Spatial Decomposition
	[-3]	IfcElements Container Structure	Element Decomposition
	[-4]	IfcClass Occurrences	-
	[-5]	PropertySets Occurrences	Property Sets for Objects
	[-6]	Listing of all Property Sets (.json)	Property Sets for Objects
Placement	[-7]	Relative Placement Hierarchy	Product Local Placement
	[-8]	Element Structure Referenced Placements	Attribute: Referenced by Placement
Geometric Representation	[-9]	Geometric Representation Type Occurrences (extra Output for Mapped Items)	Mapped Geometry
	[-10]	Description of each elements representations	Product Geometric Representation

The extraction routines are further explained below by analysing the corresponding concept templates and describing their way of implementation in the tool.

Extraction routine [-2] delivers a tree structure describing the composition of the model. It is based on the concept template of “Spatial Decomposition”.

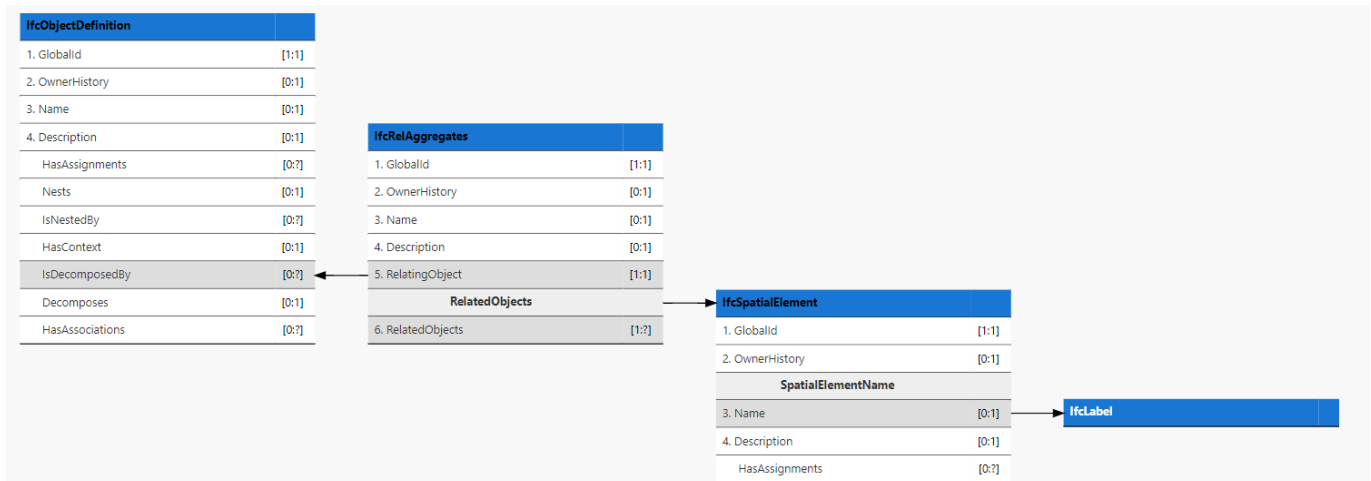


Figure 41: Concept Template Spatial Decomposition³

Routine [-2] includes a recursive function that prints a name and a type of an object, checks whether it is decomposable, gets through the attribute `IsDecomposedBy` to the relationship `IfcRelAggregates` and its related objects to the object that decomposes the first object. As this element can be decomposable again, the recursive function is re-called.

```
def recursiv(object, ind=0):
    name = object.get_info()['Name']
    print("".ljust(ind*4) + object.get_info()['type'] + "[{0}]".format(name))
    try:
        obj_rel = object.IsDecomposedBy[0]
    except:
        return
    decompose_elements = obj_rel.RelatedObjects
    for element in decompose_elements:
        recursiv(element, ind+1)
```

Listing 1: Excerpt python script implemented concept template of “Spatial Decomposition”

Optional choice [-3] is developed to analyse the concept template of “Element Decomposition” between the elements of the models. It works in a similar way as choice 2, but delivers the spatial structure of the elements contained in `IfcBuildingStoreys`.

Extraction routine [-1] merges the concept templates of “Spatial Decomposition” [-2], “Element Decomposition” [-3] and “Spatial Container”. The “Spatial Container” concept acts as connection between the concepts of “Spatial Decomposition” and “Element Decomposition”. It describes a spatial element (e.g. `IfcBuildingStorey`) as spatial con-

³ All figures representing the paths of concept templates within this chapter are based on the figures from IFC4x3 documentation (bSI - IFC4x3 Documentation (2022)).

tainer. Elements can be connected to these containers by the relationship `IfcRelContainedInSpatialStructure` (c.f. [Figure 42](#)). Combined with the other two concepts, it delivers a complete breakdown structure, based on the `IfcRelAggregates` and `IfcRelContainedInSpatialStructure` relationships. The result is a hierarchical tree structure that contains all objects. The evaluation outputs are supplemented with information about the existence of composing and contained elements and the corresponding number of these elements.

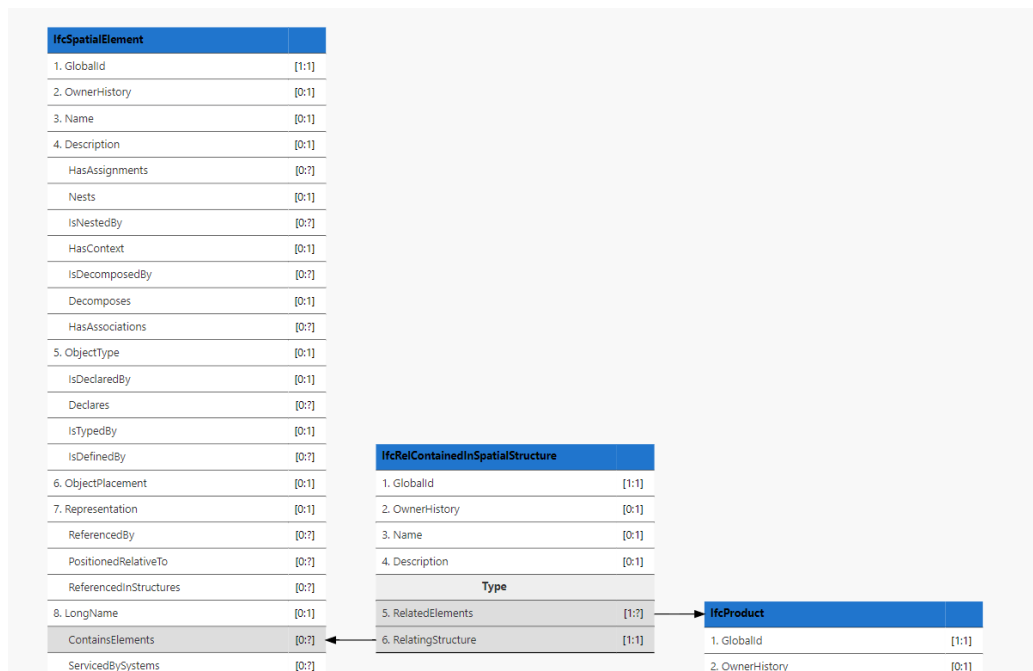


Figure 42: Concept Template of Spatial Container

Extraction routine [-4] supports the analysis of the elements. It runs through the models and checks which IFC classes are in use. It counts the number of elements that had been assigned during the output to each IFC class. The results are delivered in a csv file.

Evaluation options [-5] and [-6] investigate the property application in the models. They are based on the concept template of “Property Sets for Objects”. Extraction process [-5] delivers a csv file that describes the occurrences of each Property Set through counting the `IfcRelDefinesByProperties` (c.f. [Figure 43](#)). The results are presented in a bar plot directly attached to the process. The plot is stored in the results- folder. Extraction process [-6] selects all property sets used within a model and writes them in a json file.

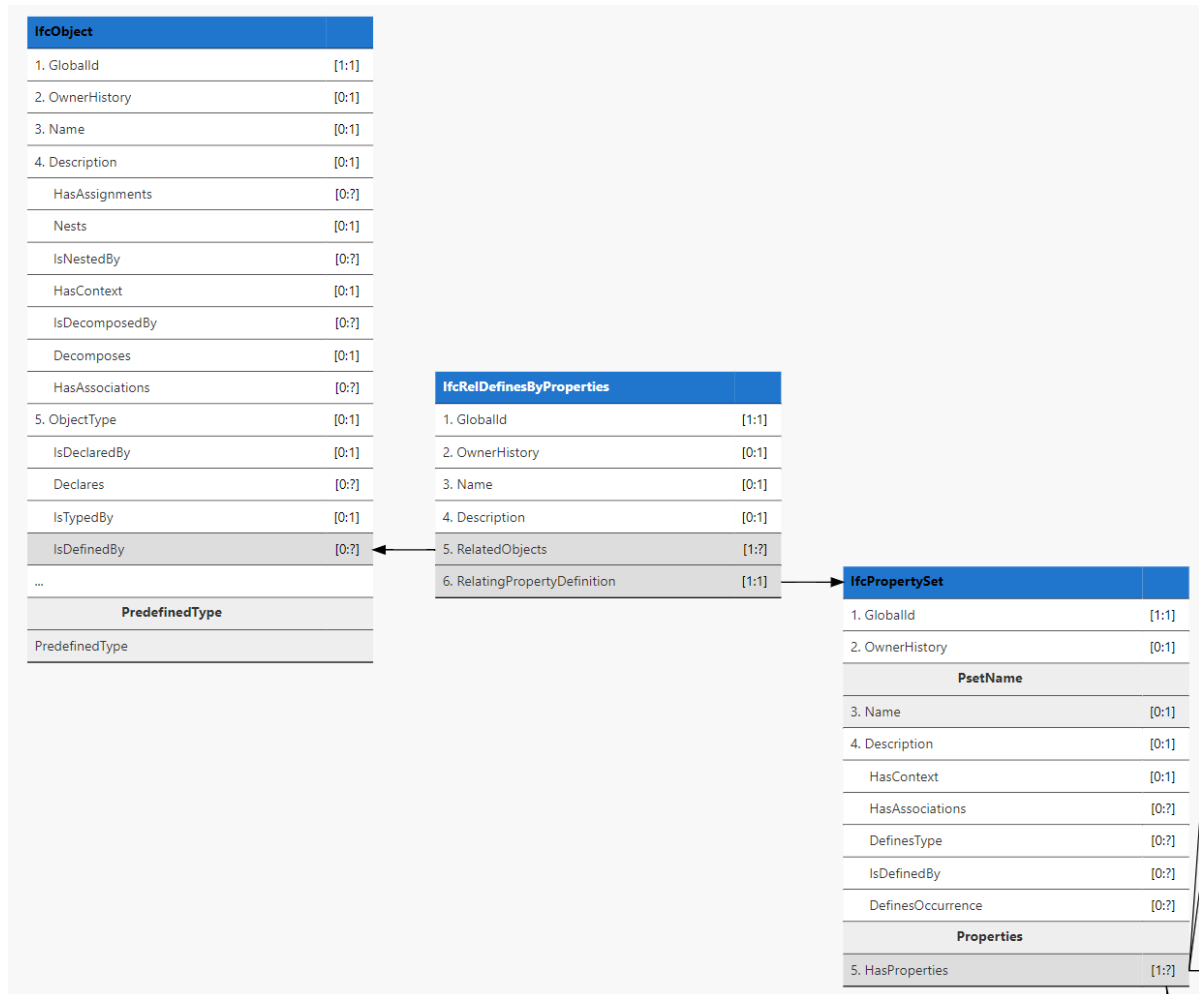


Figure 43: Concept Template “Property Sets for Objects“

The extraction option [-7] is developed to get information about the relative Placement hierarchy. The concept template “Product Local Placement” describes this application of the IFC schema (c.f. [Figure 44](#)). Extraction routine [-8] checks the link of relative placements between the elements by the attribute `ReferencedByPlacements`. The exact role of the `ReferencedByPlacements` attribute is highlighted in [Figure 44](#). The output delivers a tree structure of the relative placements of all entities in the model. This is useful for checking the parent placement of each element.

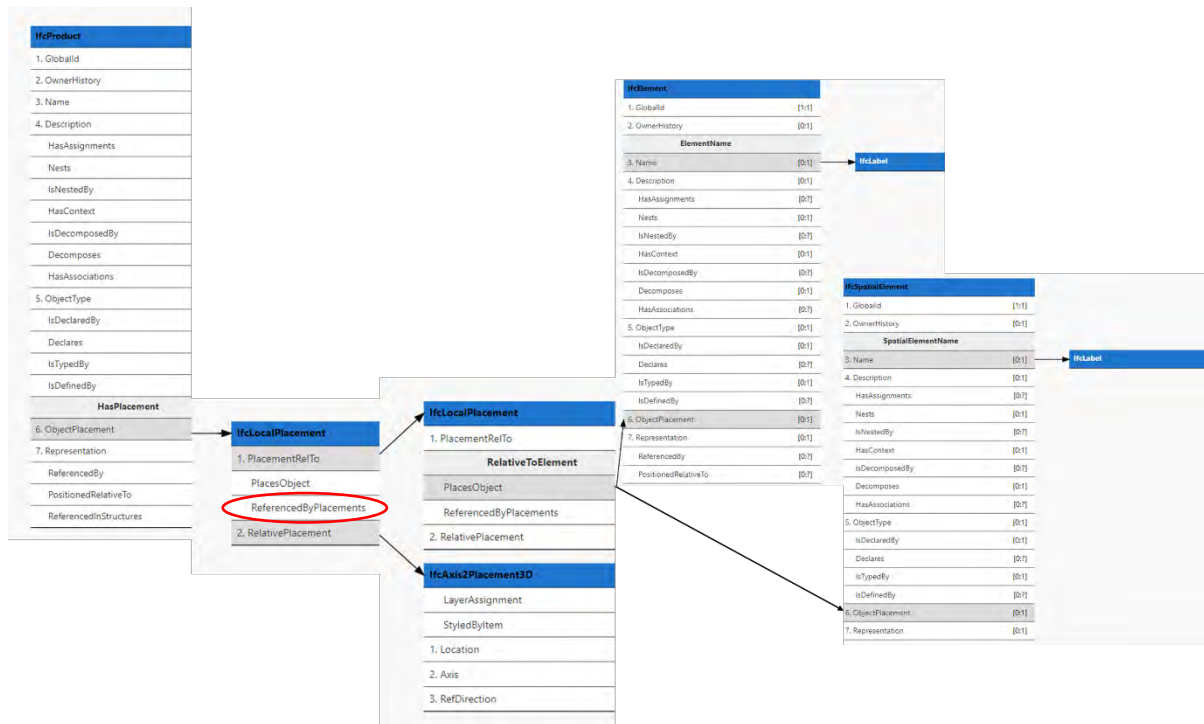


Figure 44: Concept Template “Product Local Placement”

Routines [-9] and [-10] are developed to investigate the geometric representation types of the models. They are based on the concept template “Product Geometric Representation” (c.f. [Figure 45](#)). [-9] counts all occurrences of the different types and writes the data in a csv file. [-10] runs through all elements, accesses the items of each representation and delivers information about the type and the attributes. The output text file is beneficial for quickly accessing well-structured geometry information of a specific element.

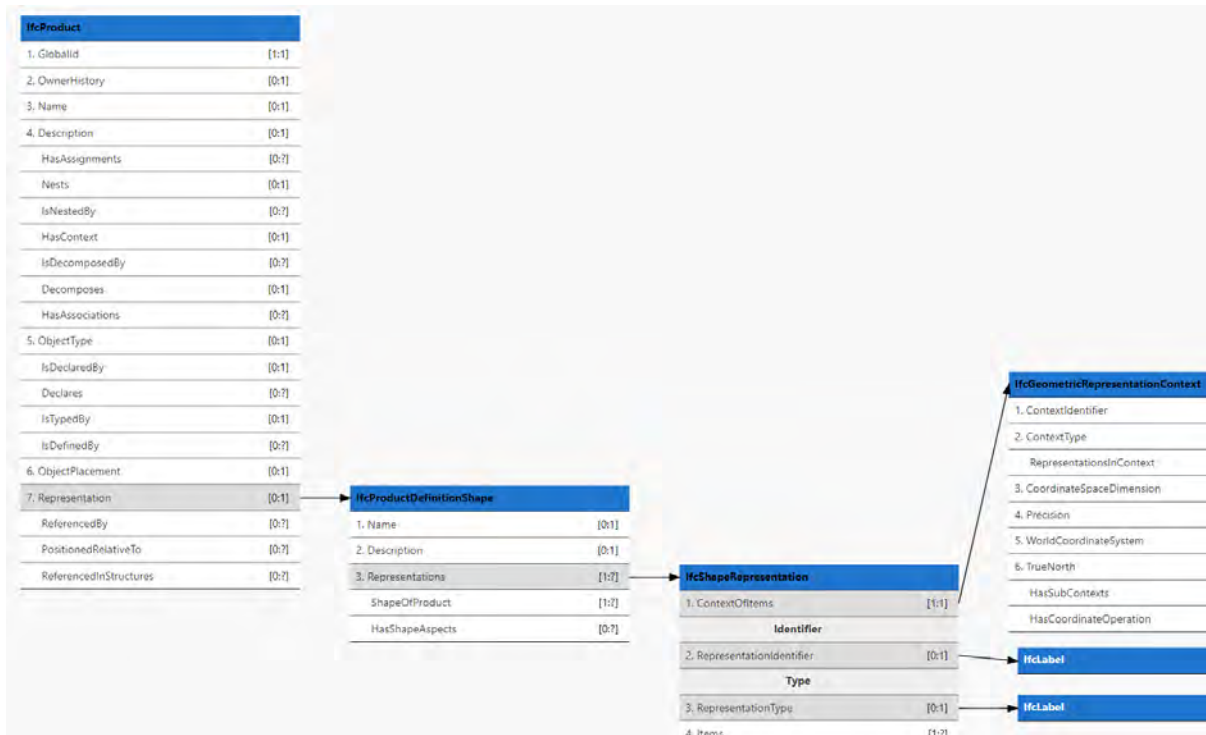


Figure 45: Concept Template “Product Geometric Representation“

For further geometric analysis it is beneficial to access more detailed information about the types of the mapped representations. This is the reason why the concept template of “Mapped Geometry” is included in extraction routine [-9]. It delivers the csv file output for all occurrences of geometric representation types and a listing of mapped geometries with the corresponding source items and their attributes. The occurrences of all types of geometric representation with the corresponding share of mapped items are plotted in a bar diagram within the evaluation tool.

The results of the evaluation tool applied on the ÜAG metro line models are presented in the following section.

4.3.4 Structure and Hierarchy of the Model

Depending on tunnel or station model, the three models are structured differently. The station models consist of different levels, which are reflected by instances of IfcBuildingStorey in the IFC models. The Atasehir station model assembles 13 and the Finans Merkezi model 21 storeys. The tunnel model contains only one instance of the IfcBuildingStorey entity.

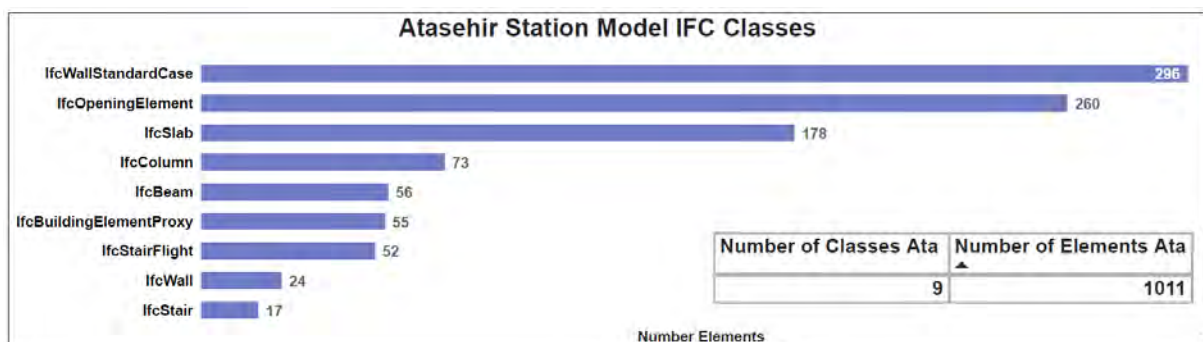
As explained in chapter 3, there is a predefined composition structure for a model in IFC2x3. The tool results show that all of the three models are following the structure given by bSI in the IFC2x3 format. The sample of the tunnel model is shown below:

```
IfcProject[2016/311079]
  IfcSite[Default]
    IfcBuilding[L06 Atasehir-Finans Merkezi İstasyonları Arası Hat Yapısı]
      IfcBuildingStorey[±0.00= (R.Ü.K.)]
```

Listing 2: Hierarchy Tunnel Model

The analysis of the element decomposition unveils a flat hierarchy within all three models. In the station models, only the stairs are decomposed by slabs and stair flights (runs). All other elements are part of the spatial containers `IfcBuildingStoreys` but are not further aggregated. The tunnel model has no hierarchy within the beam elements and the `IfcElementProxies`. None of the 1380 elements is part of another element.

The usage of the IFC classes within the models is as follows: The elements of the two station models are assigned to nine different subclasses of `IfcElement`. The two station models use a similar distribution of elements. Only the Finans Merkezi Station model is larger and includes a higher number of elements than the Atasehir model. The `IfcBuildingElementProxy` elements within the Finans Merkezi model build a pedestrian access tunnel to the station.



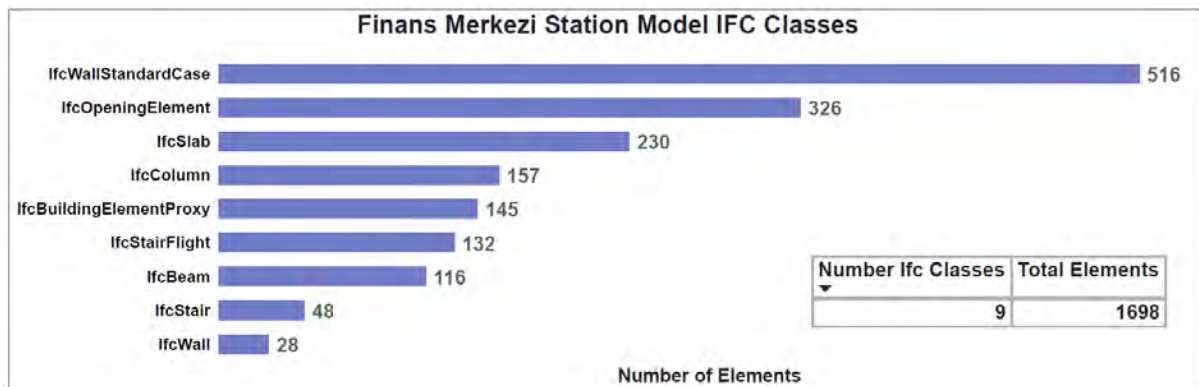


Figure 46: Station model results evaluation script [-4] – Number of elements per instantiated `IfcBuildingElement`

The tunnel model instantiates two different IFC classes. As mentioned in chapter 3.1.3, no tunnel-specific IFC definitions are available in IFC2x3. So in the structural analysis model, the tunnel segments and all parts of the cross passages are assigned to the `IfcBeam` entity definition. The reason for this is, that 3D line snapping is available for beam elements (structural framing) in Revit. This feature is beneficial for the placement of the tunnel segments at the corresponding polyline resulting from the tunnel axis section. Each section of the axis is 1.5 m long and is represented as line connecting two Cartesian points. The beam elements representing the tunnel segments are extruded along these lines. `IfcElementProxy` elements within the tunnel model are not part of the structural parts of the tunnel. They build the stationing labels and markings of the tunnel and are therefore neglected for further analysis.

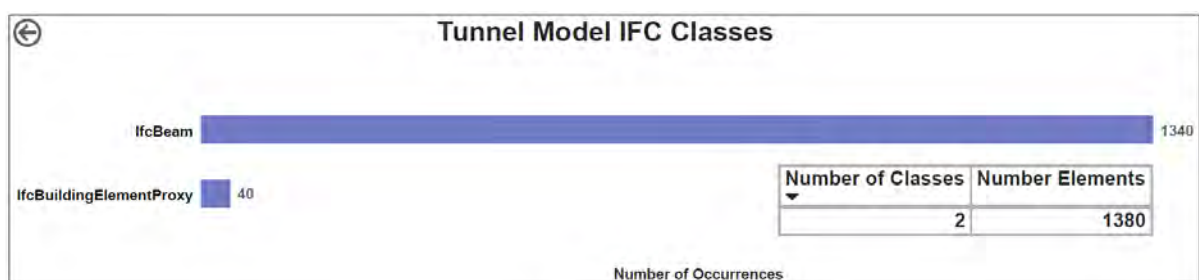


Figure 47: Tunnel model results evaluation script [-4] – Number of building elements per utilised IFC class

Property sets are linked to elements to assign additional semantic information. For example, the property sets assigned to a tunnel segment is illustrated in [Listing 3](#).

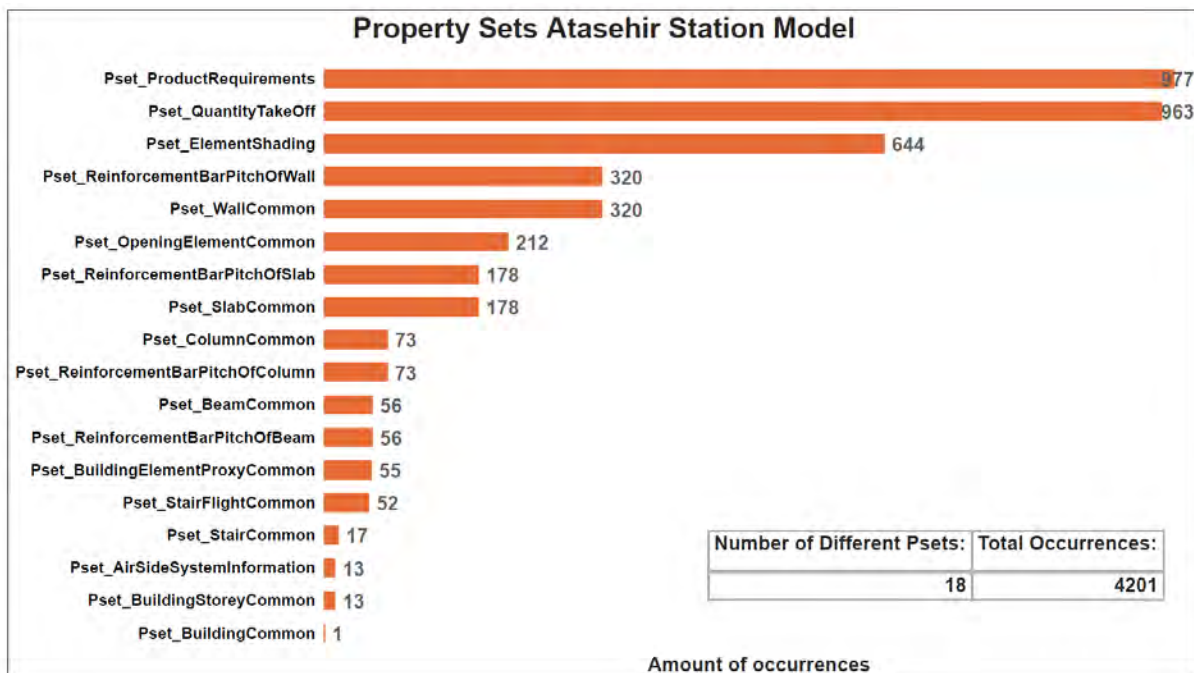
```

"Pset_ProductRequirements":{
  "Category": "Structural Framing"
},
"Pset_QuantityTakeOff":{
  "Reference": "C40_TBM"
},
"Pset_ReinforcementBarPitchOfBeam":{
  "Reference": "C40_TBM"
},
"Pset_BeamCommon":{
  "Reference": "C40_TBM",
  "IsExternal": false,
  "LoadBearing": true,
  "Span": 150.000955919826,
  "Slope": 0.205336750996114
},

```

Listing 3: Property Sets of a tunnel segment

The results of the evaluation tool in the topic of property sets are presented below. On average, every element has linkages to 4 property sets to be described. As the station models have a larger variety of instantiated class types, they also have a greater diversity of quantity sets.



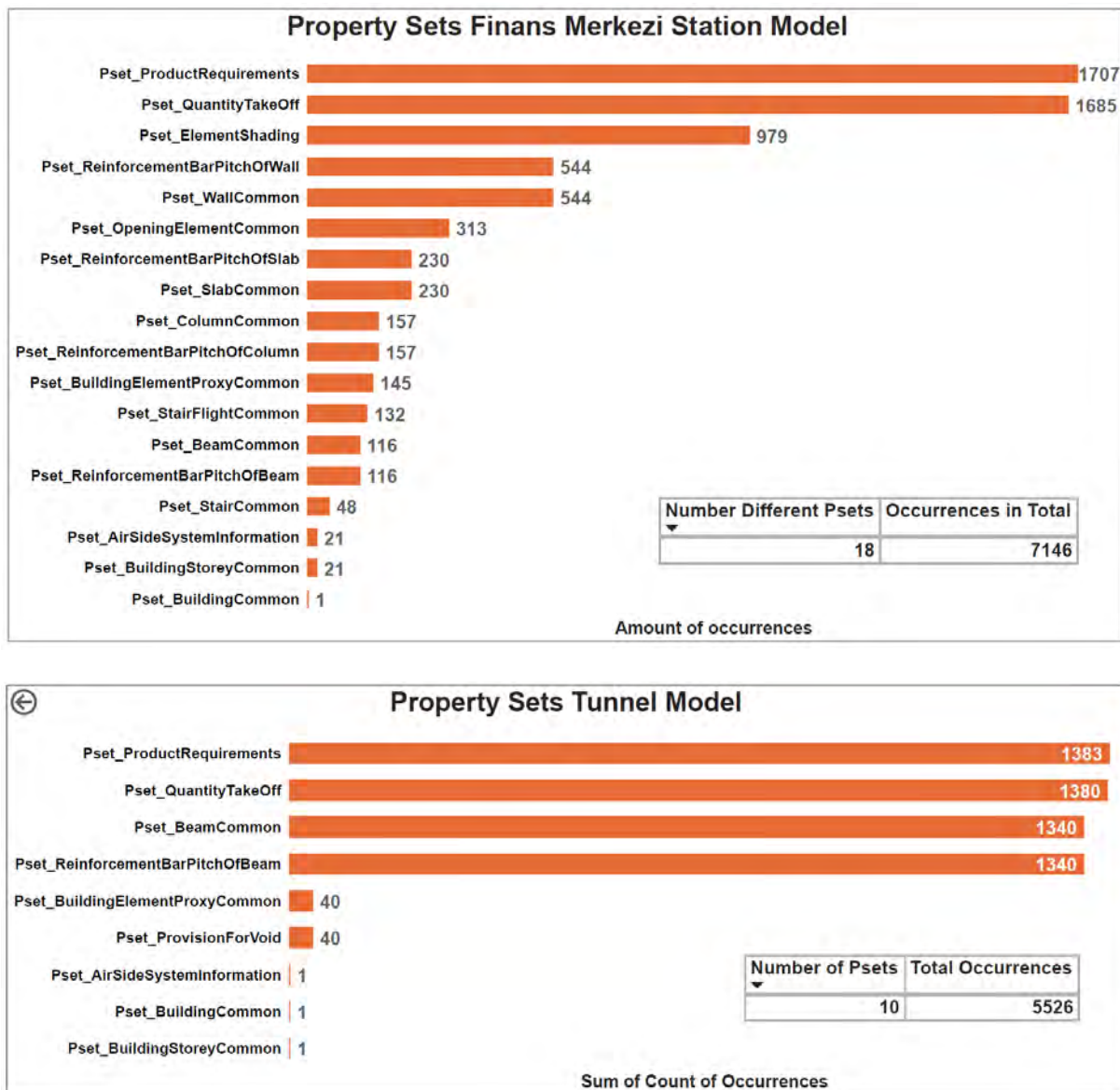


Figure 48: Property sets per model – results extraction routine [-6]

The analysis revealed that property sets used within the three models are predefined Psets by buildingSmart international. Even instances of the placeholder entity IfcBuildingElementProxy is missing additional project-specific information. Some of the property sets are applied in a new way. For example, the Pset_ProductRequirements is related to all products to assign them to one category, such as Project Information, Landings, Floors, Generic Models, Structural Framing, Walls, Levels, Runs or Structural Foundations. Pset_AirSideSystemInformation is used to store the elevation of the storeys.

4.3.5 Placement

The IFC STEP-files are investigated in a first step. As the Revit output does not support an `IfcMapConversion`, a closer look at the defined geometric representation context is taken (c.f. [Listing 4](#)). Line #113 defines the precision to be set to 0.001 and the world coordinates system to be at 0,0,0 (defined in line #6) (Dion Moul, 2019). These settings are the same for the two station and tunnel models. The models consist of 4 optional geometric sub-contexts (Axis, Body, Box and FootPrint), which are further analysed in the geometric representation section.

```
#6= IFCCARTESIANPOINT((0.,0.,0.));

#110= IFCAxis2PLACEMENT3D(#6,$,$);
#111= IFCDIRECTION((6.12303176911189E-17,1.));
#113= IFCGEOMETRICREPRESENTATIONCONTEXT($,'Model',3,0.001,#110,#111);
#116= IFCGEOMETRICREPRESENTATIONSUBCONTEXT('Axis','Model',*,*,*,*,#113,$,.GRAPH_VIEW.,$);
#118= IFCGEOMETRICREPRESENTATIONSUBCONTEXT('Body','Model',*,*,*,*,#113,$,.MODEL_VIEW.,$);
#119= IFCGEOMETRICREPRESENTATIONSUBCONTEXT('Box','Model',*,*,*,*,#113,$,.MODEL_VIEW.,$);
#120= IFCGEOMETRICREPRESENTATIONSUBCONTEXT('FootPrint','Model',*,*,*,*,#113,$,.MODEL_VIEW.,$);
```

Listing 4: `IfcGeometricRepresentationContext` of TBM model

For further information, the IFC georeferencing has been analysed in BlenderBIM. The origins of the model coordinate systems are each located on the height of rail top level. The figures show the location of the coordinate system origins in each model.

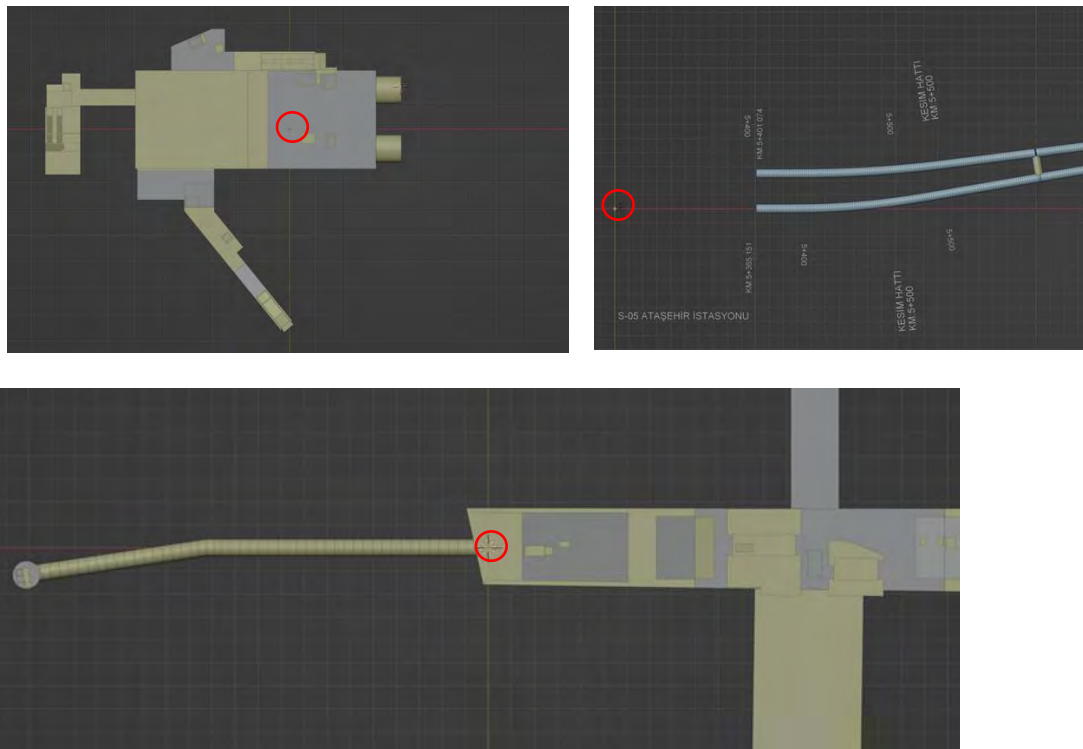


Figure 49: Placement of Projects Coordinate Systems of each model

As the distances between the stations are shorter than a few kilometres, the geodetic coordinate reference system can be projected directly to the projects' coordinate system. If the distances between the stations are very large, a scale must be added to the mapped geodetic coordinates to ensure that the actual distance on the Earth's ellipsoid and the distance in the mapped coordinate system match. (IFC Rail Project, 2019; Michel Rives et al., 2020).

Before analysing the structure of the object placement, it is reasonable to inspect the bSI standards concerning this topic:

- *IfcSite shall be placed absolutely within the world coordinate system established by the geometric representation context of the IfcProject*
- *IfcBuilding shall be placed relative to the local placement of IfcSite*
- *IfcBuildingStorey shall be placed relative to the local placement of IfcBuilding*

(bSI - IFC2x3 Documentation, 2020)

The results is that all the three models follow the standards given by the schema documentation. The world coordinate system of each project is defined in point (0,0,0). As explained in chapter 3.1.2, the conversion between the world coordinate system and a local one works with *IfcAxis2Placement3D*. If the attribute *PlacementRelTo* in a local placement remains empty, the tool generates an output containing the feedback of an absolute placement. As can be seen in the example output file of the Atasehir Station (cf. [Figure 50](#)), *IfcSite* is placed absolutely in the world coordinate system, *IfcBuilding* is relatively placed to *IfcSite* and *IfcBuildingStorey* is placed relatively to *IfcBuilding*. This is the case for all three models.

```

IfcProject[2016/311079]
project world coordinate system is defined in cartesian point: (0.0, 0.0, 0.0)
TrueNorth: 6.12303176911189e-17
y-Axis: 1.0

  IfcSite[Default]
  IfcSite has absolute Placement
  z-Axis: [0. 0. 1.]
  Location: [4.24635854e+07 4.53992744e+08 0.00000000e+00]
  RefDirection: [0.59957127 0.80032137 0.    ]

    IfcBuilding[Ataşehir İstasyonu]
    Placed relative to: IfcSite[Default]
    z-Axis: [0. 0. 1.]
    Location: [4.24635854e+07 4.53992744e+08 0.00000000e+00]
    RefDirection: [0.59957127 0.80032137 0.    ]

      IfcBuildingStorey[-1.84 PERON ALTI KATI (SSL)]
      Placed relative to: IfcBuilding[Ataşehir İstasyonu]
      z-Axis: [0. 0. 1.]
      Location: [ 4.24635854e+07 4.53992744e+08 -1.84000000e+02]
      RefDirection: [0.59957127 0.80032137 0.    ]

```

Figure 50: Output Section of Ataşehir Station Model

The models are structured differently in terms of their IfcBuildingStorey placements. Within the station models, the storey coordinate systems are shifted along the z-Axis to the different levels.

For instance, the Ataşehir Station model is divided into 13 Storeys. The location of the local coordinate system is dependent on the difference to the rail top level. The rails and the rail superstructure are part of the IfcBuildingStorey of “-1.84 PERON ALTI KATI”.

Some of the other storeys include only a very few elements or are not located reasonably from an engineering point of view. An example are the following two storeys, where the lower storey (green markings) has a height of 10 cm and contains few elements.

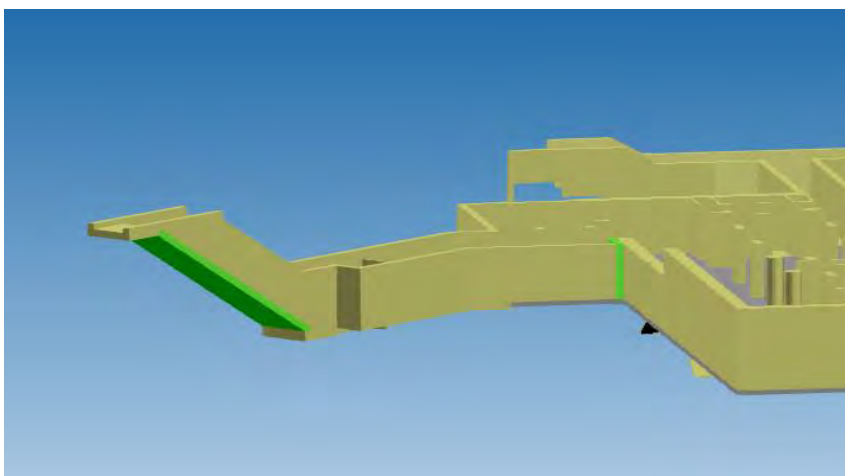


Figure 51: Example Storeys Ataşehir Station

The Finans Merkezi Station model exists out of 21 storeys. Three of the storeys describe the rail level. The `IfcBuildingStorey`, which contains the rails (marked in green in [Figure 52](#)) is placed -39.45 m below the rail top level. The `IfcBuildingStorey` “Rail top Level” is located exactly like the `IfcBuilding` and contains three small basic wall elements. The slabs and other parts of the track superstructure are part of the storey “R.Ü.K”, which builds the rail top level.

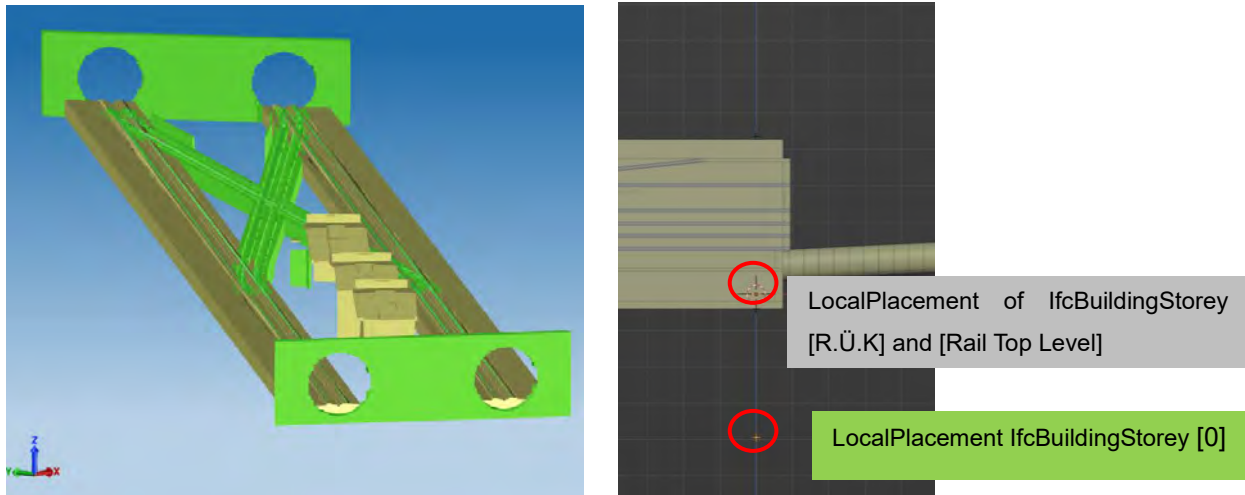


Figure 52: Finans Merkezi Station model: `IfcBuildingStorey` [0] (green) and `IfcBuildingStorey` [Rail Surface] (yellow) with different relative placement

As the tunnel model contains one `IfcBuildingStorey`, which is located in the same coordinate system as the `IfcBuilding` and `IfcSite`, the placement of the storey does not have to be translated to another coordinate system. The beam elements are placed by local placement relatively to the `IfcBuildingStorey`. The long red line (cf. [Figure 53](#)) builds the x-axis of the spatial container (`IfcBuildingStorey`) coordinate system. The first tunnel segments, which are located next to the Atasehir Station, are placed closely to the local x-axis. As shown in [Figure 53](#), the local coordinate system of the first tunnel segment seems to be placed on the global x-axis, but it is located with a slight offset to the axis (varying y and z value). This offset increases by each segment with advancing distance to Atasehir station.

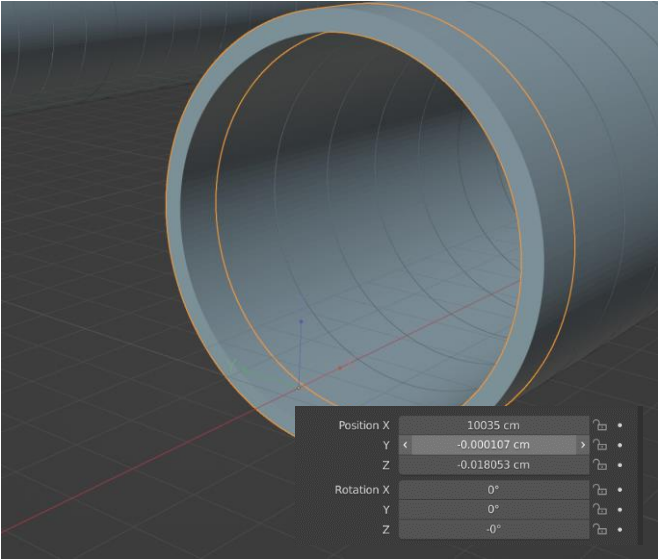


Figure 53: Object Placement of Beam elements

In the area of the cross passages, the regular local placements of the beam elements intermits. As it can be seen in *Figure 54*, the position of the local coordinate system changes in z coordinates.

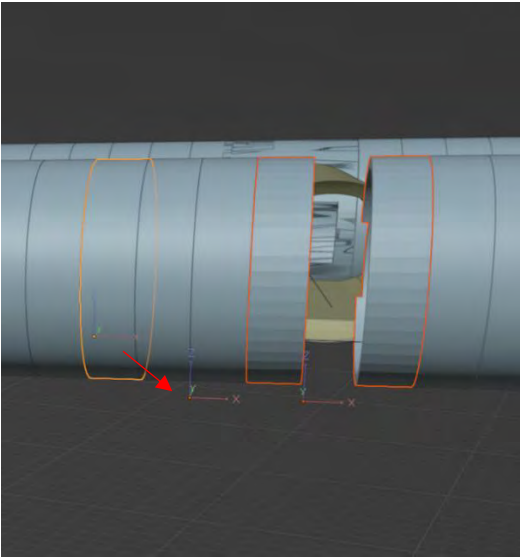


Figure 54: Beam Placement at Intersection with cross passage

The same situation appears with the beam elements in the cross passages. The Innerline Top element is placed outside the own element and the void rectangle element has its relative location within the element.

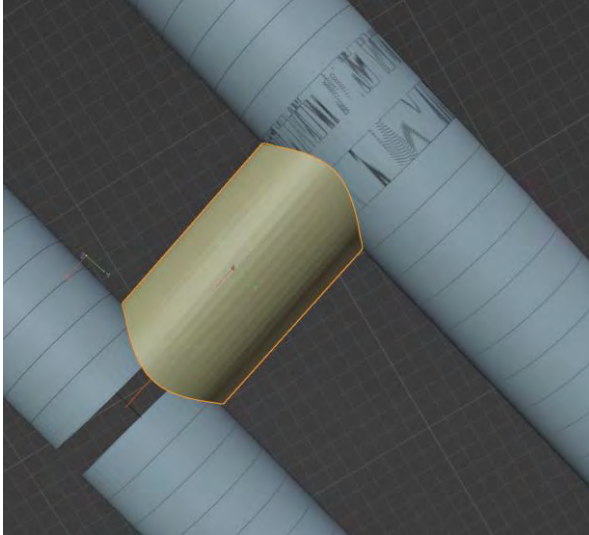


Figure 55: Placement of elements coordinate system at the cross passage

The results in the topic of element placement show that the IfcElements in the station models are all relatively placed to one of the IfcBuildingStoreys. In case of IfcOpeningElements in walls and slabs or aggregated staircases, these elements are relatively placed to their parent elements.

The tool results of the tunnel model deliver different findings. In this case 34 of the 1380 elements are placed relatively to the IfcBuildingStorey. The remaining elements are attached to the IfcBuilding of the tunnel model. Spatial decomposition defines the composites to be placed relative to the parent structure. For spatial container, the placement of the elements can vary. Therefore, the placement strategy of the tunnel model is following the standards set by bSI.

4.3.6 Geometrical Representation of the Model

The tool delivers the outcome, that in the Finans Merkezi Station model 48 and in the Atasehir Station model 17 elements are not geometrically represented at all. These elements are part of the IfcStair compositions, so they are represented by their components. Within the tunnel model, all elements except for IfcSite, IfcBuilding and IfcBuildingStorey have a geometrical representation.

The plots generated by the tool are visualised in [Figure 56](#). The tunnel IFC file includes a large number of geometric representations (2998) relatively to its number of elements (1380). This makes up a factor of 2.17 times the number of elements. Compared to the station models, which have a factor lower than 1.5, the value of the tunnel model is significantly higher.

As explained in Chapter 3.1.2, the geometric representation of models can be divided into two main groups: implicit (yellow marking [Table 9](#)) and explicit (blue marking) geometric representation methods. For further analysis, the occurred types of representation are assigned to one of the two groups by utilising the bSI definitions. Implicit geometries are `IfcExtrudedAreaSolid` (sweeping a bounded planar surface by a given direction and depth), `IfcBooleanResult` (usage of Boolean operators) and `IfcBooleanClippingResult` (a special case of `IfcBooleanResult`). Explicit geometries are created using `IfcFacetedBrep` (planar faces and straight lines) and `IfcFaceBasedSurfaceModel` (set of connected face sets). `IfcMappedItem` is used to benefit from an existing representation and places it as another representation item at a new position. (bSI - IFC2x3 Documentation, 2020) Therefore, instances of `IfcMappedItem` are investigated in the next deeper step. They are split up into their initial geometry of the mapped source and added to the corresponding representation method. Instances of `IfcPolyline` are the axes of the wall and beam elements' shape representation.

[Table 9](#) gives an overview of the representation types within the three models. It describes the application of the methods in relation to the elements.

Table 9: methods applied to elements (blue: explicit, yellow: implicit)

Representation Method	IFC Classes utilising the Method
<code>IfcMappedItem</code>	Column, Beam, ElementProxy
<code>IfcFacetedBrep</code>	Beams, OpeningElement, Wall, Slab, StairFlight
<code>IfcBooleanClippingResult</code>	Beam, WallStandardCase, Slab
<code>IfcBooleanResult</code>	Slab
<code>IfcExtrudedAreaSolid</code>	Slab, Wall, Beam, OpeningElement
<code>IfcFaceBasedSurfaceModel</code>	ElementProxy (as Rail)

The ratio of implicit geometry representation in the sub-context of body representation for each model (excluding non-body representation `IfcPolyline` and `IfcTrimmedCurve`) is 88% in the Atasehir model, 71% in the Finans Merkezi model and 98% in the tunnel model.

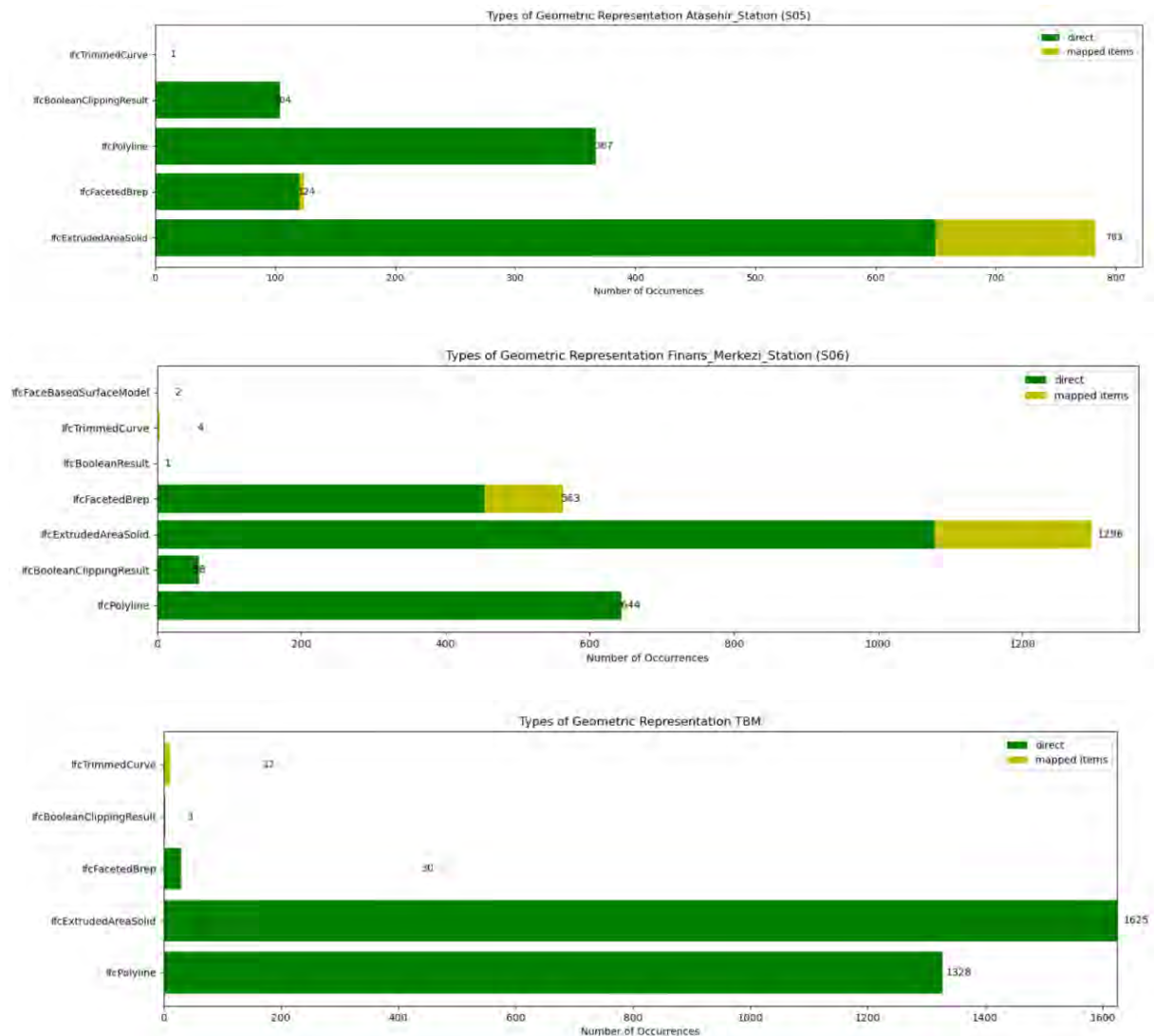
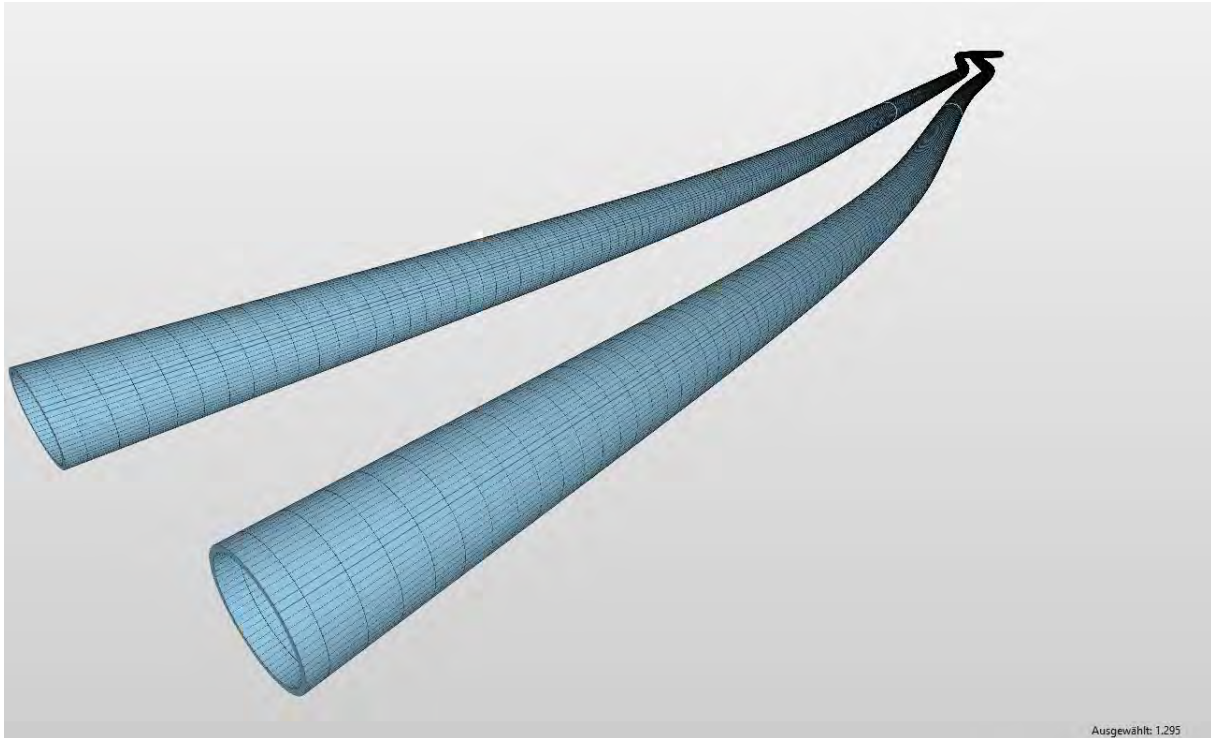


Figure 56: Results extraction routines [-9] and [-10] - geometric representation

As TBM tunnels in general often compose a single segment that is used repetitively along the track axis, the geometry of this element should only be represented once to decrease storage issues. By utilizing the concept of `IfcObjectType`, the single element can be instantiated, rotated and placed many times without storing its geometric shape more than once. (Michel Rives et al., 2020). This idea should be pursued by the representation of a tunnel model.

Instances of `IfcMappedItem` are applied 12 times for beam elements. This number shows, that the beam segments representing the tunnel are not referring one predefined geometric definition. Additionally, `IfcFacetedBrep` is used 30 times for beam segments and `IfcBooleanClippingResult` 3 times for beams. Consequently, most of the

tunnel segments are represented by extruded implicit geometry (IfcExtrudedArea-Solid). According to this, [Figure 57](#) visualises all elements, which have been detected as extruded geometries by the Solibri Model Checker.



[Figure 57](#): View of elements with extruded geometry in Solibri

As mentioned in the use case of visualization (c.f. [Figure 35](#)), the tunnel representation has inconsistencies within the cross passages, which do not occur in the original Revit model. Further analysis reveals that the situation, which is outlined in the following paragraph is likely to cause the problem. It is a suitable example for misinterpretation of implicit geometry.

The evaluation tool (script [-9]) unveils that each tunnel segment has two representations. One shape representation is of sub context “Axis” and the other one is of sub context “Body”. [Figure 58](#) shows a sample intersection with faulty interpretation in the IFC file. The tunnel segment is visualised, but cut off from two sides. [Figure 59](#) and [Figure 60](#) show the procedural development process of the corresponding geometry in Revit. The resulting geometry within two steps is a Boolean Clipping Result. The rounded shape in [Figure 59](#) is the cross section of the corresponding tunnel segment and builds the first operand within the Boolean operation. The two rectangular solids are the second operands each of the double applied operator “difference”. The expected shape is shown in [Figure 61](#). As the resulting shape differs from the expected one, it is likely, that

the export process within Revit leads to the following misinterpretation in the geometry. The geometry developed in Revit, cuts off the tunnel segments at the inner planes of the rectangular solids (green arrows in [Figure 59](#)). The IFC-based visualisation cuts off the tunnel segments at the outer intersection of the corresponding geometries (red arrows). It is likely, that this situation causes the gaps in the tunnel segments representation.

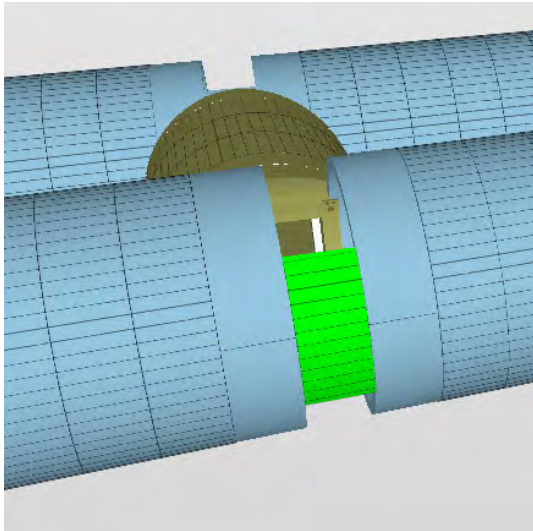


Figure 58: misinterpreted Element 2373225 in Solibri Viewer

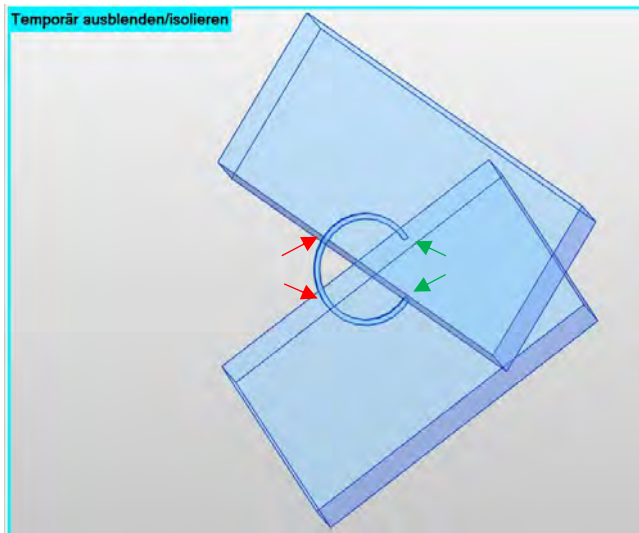


Figure 59: procedural process of the geometry in the original Revit file

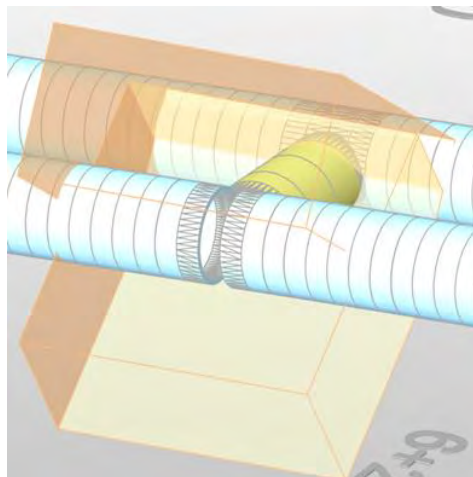


Figure 60: Further explanations to the Boolean operations (yellow rectangular solids: second operands of the difference)

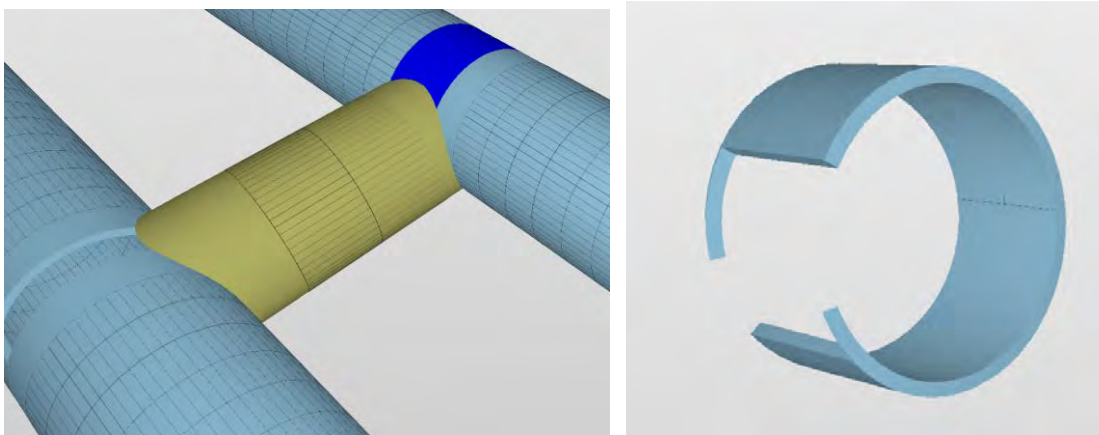


Figure 61: expected geometry (highlighted dark blue); expected geometry isolated (right)

In addition, the misinterpretations occurs at all intersections, which are represented through implicit geometry (`IfcBooleanClippingResult`). In this IFC model, the issue is represented correctly only once. In this case, the corresponding segments are represented as explicit geometries (`IfcFacetedBrep`).

4.3.7 Outcomes of the Analysis Concerning Schema IFC2x3

In the following, the results of the evaluation tool and the applied use cases are used to determine whether the current IFC2x3 version is suitable for infrastructure models.

Within this selection of use cases and models, the use cases are only applicable to the station models. Applying the use cases to the tunnel model led to problems such as inconsistencies in the length of the segments and visualisation issues occurred.

The analysis of the hierarchic aggregation structure showed that the standards from bSI were met in the three models. The structure of `IfcBuilding` to `IfcBuildingStorey` is suitable for the station models. The tunnel model is aggregated by only one spatial container of `IfcBuildingStorey`. This limits features, such as flexibility in visualisation or structuring of semantic information. An enhanced hierarchic structure of the tunnel model is delivered through a later version of the model. Within this model, the two main tunnels are contained in one `IfcBuildingStorey` and the cross passages are assembled in a second spatial container. This is an improvement of the spatial structure of the model. As the two storeys within the model are located on the same elevation, the naming of spatial container being “storeys” may lead to confusion.

The IFC classes assigned to the elements are suitable to reflect their service intend inside the station models. For rail specific elements, however, the unspecific IFC class

IfcBuildingElementProxy is assigned but not specified further. Concerning the tunnel model, no suitable IFC classes were available within the IFC2x3 schema. The workaround by using the IfcBeam elements as structural framing tunnel segments seems to work well in the chosen BIM authoring tool, but assigns these objects a misleading semantic definition. Assigning the track side text labels, which contain the stationing information of the tunnels, to IfcBuildingElementProxy is not reasonable. It induces 40 elements within the model, which will not be built in reality.

All property sets applied are predefined in the IFC documentation. As these property sets do not cover all semantics implemented in the authoring tool, numerous properties are excluded while assembling the property sets. This results in a loss of information during the export process to IFC and leads to an insufficient semantic basis for downstream tasks.

The placement hierarchy of the models follows the bSI standards, which means that IfcBuildingStorey is placed relatively to IfcBuilding, which is placed relatively to IfcSite. All elements contained within a spatial structure are usually placed relative to their container. The placement strategy is suitable for the station models. As the tunnel segments within the tunnel model cannot be placed relative to the axis within IFC2x3, they are placed relative to their spatial container in a local coordinate system. This leads to a complex, error-prone placement system for the tunnel segments. Consequently, in the area of cross passages, this results in gaps the regularity of the placement [Figure 54](#).

In case of geometry representation, there are no major issues concerning the infrastructure topic within the station models. On the other hand, the tunnel IFC model contains deficiencies within the areas of the cross passages. These are related to the different sub contexts. As the IFC model contains only one geometric sub context to represent bodies, it has no flexibility to adapt corresponding use cases, if the implicit geometry is not interpretable.

Summarising, within the hierarchic structure, the IFC class selection, the placement and the geometric representation the IFC2x3 schema does not provide a sufficient basis to apply the tunnel model to a variety of use cases. The investigation of the clash detection, the quantity take off and the visualisation of the tunnel model support this

statement. In the case of the station models, less problems occur within the examined aspects.

However, the potential of the IFC2x3 schema is not fully exploited in the models. Prior to relying on the IFC models for the BIM process, a number of improvements could be applied on the models to enhance their capability of meeting the requirements.

A lot of properties are implemented in the authoring tool which were excluded from the information transfer to the IFC model. When selecting the IFC export option “export Revit properties”, the IFC model enriches its semantic basis. The evaluation tool results of the new exported IFC file are shown in [Table 10](#). The bSI property sets are named starting with “Pset_”; the remaining properties are named by Revit. The property groupings highlighted in yellow describe the tunnel segments represented through IfcBeams in IFC. The total number of applied property groups increased up to 17745. This is three times higher than number of property sets in the original IFC file. This demonstrates the high semantic potential of the IFC file after a reasonable export process has been carried out.

Table 10: Property Sets of the TBM file if Revit properties are included

PropertySet Name	Amount of occurrences
Pset_BuildingCommon	1
Allgemein	2
ID-Daten	1372
Sonstige	1382
Sonstige(Type)	1
Pset_AirSideSystemInformation	1
Pset_BuildingStoreyCommon	1
Pset_ProductRequirements	1
Abhängigkeiten [dependencies]	1380
Abmessungen [measurements]	1380
Abhängigkeiten(Type)	1
Grafiken(Type)	1
ID-Daten(Type)	1
Pset_BeamCommon	1339
Pset_QuantityTakeOff	1379
Pset_ReinforcementBarPitchOfBeam	1339
Geometrische Position	1339
Konstruktion	1335
Materialien und Oberflächen	1323
Phasen	1379
Text	1329
Tragwerk	1339
Pset_BuildingElementProxyCommon	40
Pset_ProvisionForVoid	40
Grafiken	40
Σ	25
	17745

Since it is not recommended to export all Revit properties by default (as carried out in this example) due to a significant increase in data size (Autodesk, 2022), the required properties should be grouped in user-defined property sets. To define the property sets, the file *DefaultUserDefinedParametersSets.txt* has to be adapted to the project-specific requirements and the option „Export user defined property sets“ has to be selected in the export process. (buildingSMART Türkiye, 2022)

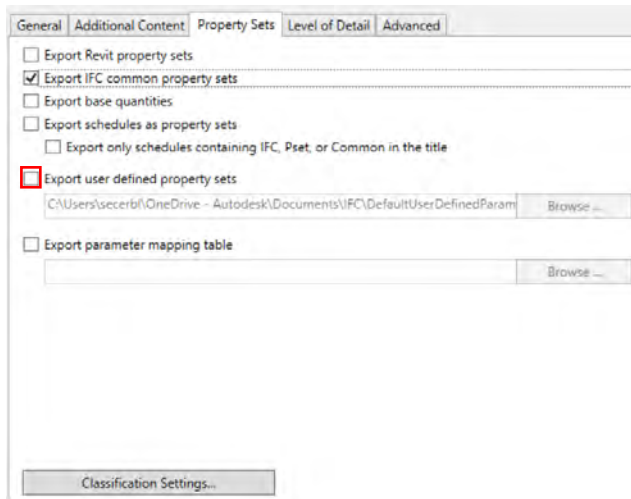


Figure 62: Screenshot IFC export options Revit (Autodesk, 2022)

Including the following semantics in well-structured property sets in the model would enrich the data basis: The property group “constraints”, for instance, provides the offset in z direction to the level of its spatial container (IfcBuildingStorey or IfcBuilding) at the start and the end point of each tunnel segment. The property group “Identity-Data” delivers the corresponding ID of the tube (line 1 or line 2) or the ID of the cross passage. However, there is one expressive information missing in the model: the positioning along the track axis. Since stationing along the alignment is not supported by IFC2x3, a numbering of the tunnel segments within a section in each tunnel could be a useful extension to have a better understanding of the placement of the element. The Revit property group “construction” contains strong semantics about the construction status of the element, such as completion percentage, production status, projects quantities and the corresponding work breakdown structure (WBS) of the element. Transferring the available 4D data to the IFC-based projects’ exchange process would increase the models capabilities towards a vendor-neutral and open process management.

A second attempt to transfer the semantics to the IFC file is mapping of the Revit instances to the definitions of IfcElements in the IFC schema. The mapping can be modified through the Revit settings “IFC Export Classes” or through adjustments in the IFC mapping file [Figure 63](#). (Trzeciak & Borrmann, 2018; buildingSMART Türkiye, 2022)

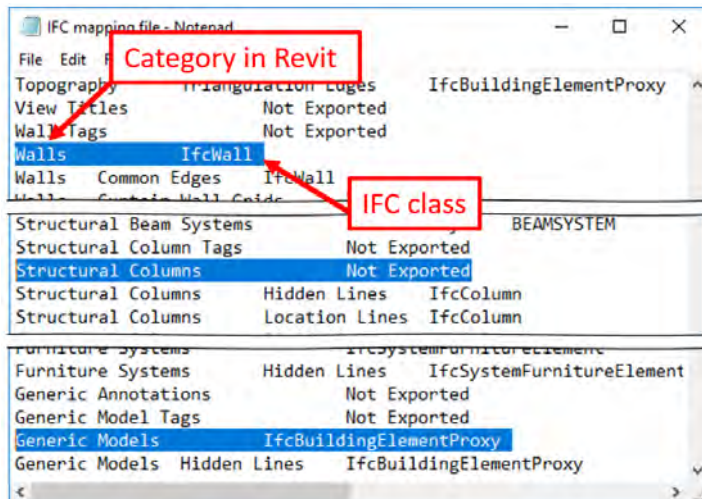


Figure 63: Sample mapping file (Trzeciak & Borrmann, 2018)

There are numerous options for a possible mapping, some examples are given in the following. The Revit family “Model Text” of type “400cm” is mapped to be `IfcBuildingElementProxy`. This could be changed to “Not Exported” to inhibit the stationing labeling being part of the IFC model. The structural framing elements representing the tunnel segments are mapped to be `IfcBeams`. They are divided in different types in Revit. For example, instances of the type “C30_C6_Tunnel_Bottom” could be mapped to `IfcSlab` as they represent the slabs in the cross passages. In an alternative approach all tunnel segments could be mapped to `IfcBuildingElementProxy`. Extending the class through a user-defined type and meaningful property sets, a suitable class could be created.

In the context of geometric representation, extending the geometric sub contexts by an explicit body representation could be beneficial. In detail, this might help to advance the representation of the tunnel intersections in IFC and avoid the misinterpretation identified. Revit provides two options to modify the geometric representation within the IFC file (Figure 64). The option “Allow use of mixed “Solid Models” representation” activates the combination of Brep and extruded geometries within an entity. This may lead to an improved representation, but is out of scope of the standard IFC schema and requires further agreements (Autodesk, 2022). However, selecting this setting does not influence the geometric representation of the tunnel model. This is in close agreement with the literature. (Trzeciak & Borrmann, 2018) Since the IFC2x3 tunnel model does not contain any tessellated geometry, the second optional geometric setting “Keep Tessellated Geometry as Triangulation” does not apply any changes to the IFC geometry either.

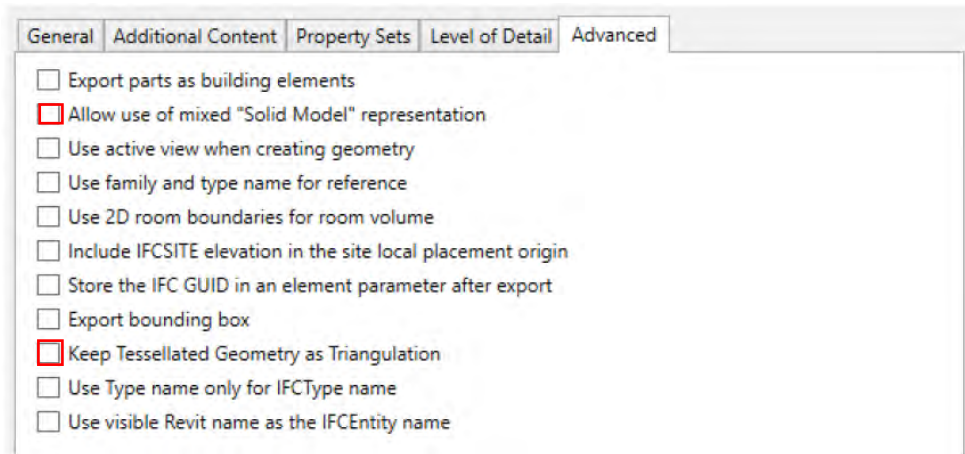


Figure 64: IFC Export settings Revit

The model contains a high potential in unexploited semantics in the authoring tool, which can be improved in the IFC model. The IFC2x3 schema covers options to enhance the geometric representation of the error-prone areas within the model. Thus, they are not accessible through simple adjustments of the obvious export settings in Revit. Adapting the hierarchy of the tunnel model to a suitable spatial breakdown structure is not possible within IFC2x3, because the flexibility in the structure of `IfcBuilding` and `IfcBuildingStorey` is limited. A linear reference system along the track axis would be a suitable placement solution for the tunnel segments. Since this feature is not covered by IFC2x3, the placement strategy applied in the tunnel model already exploits the full potential of this IFC version.

5 Evaluation of IFC4x3

The following chapter focuses on the transfer of the results from the IFC scheme comparison (chapter 3.1.4) to the example project in order to evaluate the contribution of the IFC4x3 schema to the infrastructure assets. To backup the theoretical considerations with practical examples parts of the tunnel model will be remodeled, exported in IFC4x3 and analysed by the evaluation tool.

5.1 Methodology

The results from the case study show that infrastructure-related topics are challenging to include in the IFC2x3 schema. This requires a lot of workarounds and creative solutions. Additionally, some of the identified issues, such as the placement strategy, cannot be resolved within IFC2x3.

The following section analyses which problems and intricacies related to hierarchy, semantics, object placement or geometry could be improved by the future standard release of IFC4x3. Since most of the issues were identified in the tunnel model, the main part of the investigation focuses on this model. The methods applied for this step include (1) referring the proposals by bSI to the specific case of the tunnel model and (2) remodeling particular parts of the model to produce an IFC4x3 export file, which can be investigated further through the evaluation tool and compared to the outcomes of chapter 4.3.

As implementing the whole model with the detailed cross passages in Civil 3D would exceed the scope of this work, a basic version of the model is implemented to investigate particular parts of the model. The procedural development process of the model is as follows: The alignment data of the two tunnel axes is imported to Civil 3D from a Landxml file and selected as baselines of one corridor each. Since it is the most basic option for later steps, an assembly consisting of two elements is built (*Figure 65*). This geometry does not include holes or voids, which leads to a simple extrusion process. The assembly forms the cross section of the tunnels. In the first step, the “Tunnel Segments” are placed with a frequency of 1.5m along the alignments (*Figure 66*). In the second step, the assembly “Tunnel Segment” is swept along the alignments (*Figure 67*).

The resulting combined model (TBM_Assembly) of frequently placed cross sections and extruded solids is exported through the IFC Infra Exporter to IFC4x3.

Due to working memory issues representing the combined model, the resulting extruded solids are copied to a second model. This model (TBM_GeomRep) is used for geometry analysis only. To improve the geometry model and make it more accurate, the cross passages are transferred from the Revit model and implemented as an external reference (xref). The resulting geometry model can be seen in [Figure 68](#).



Figure 65: Assembly "Tunnel Segment" (only white areas are part of the geometry)

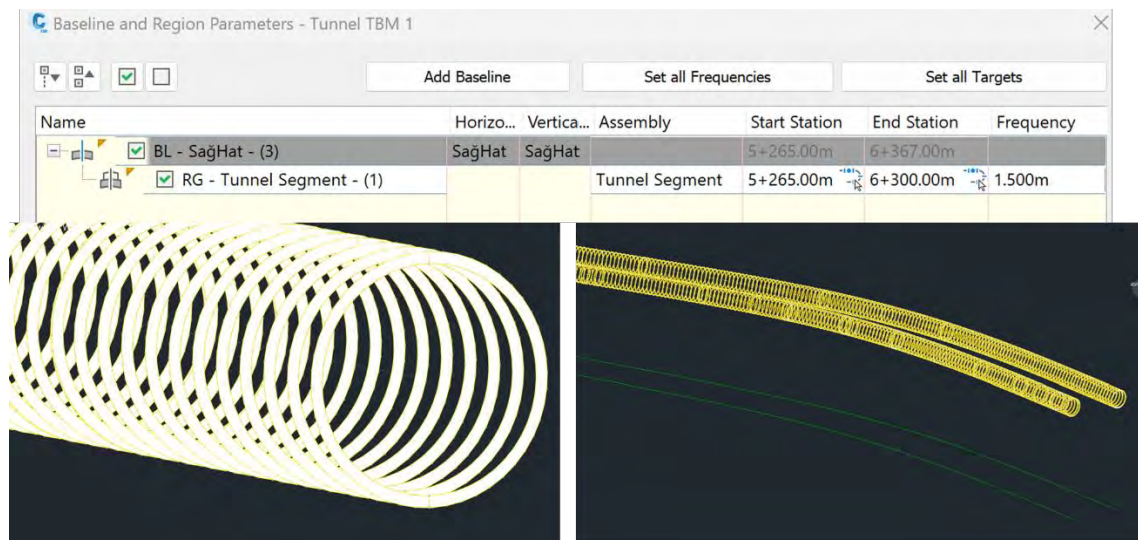


Figure 66: Placement of Assembly "Tunnel Segment" along the alignments with a frequency of 1.5m

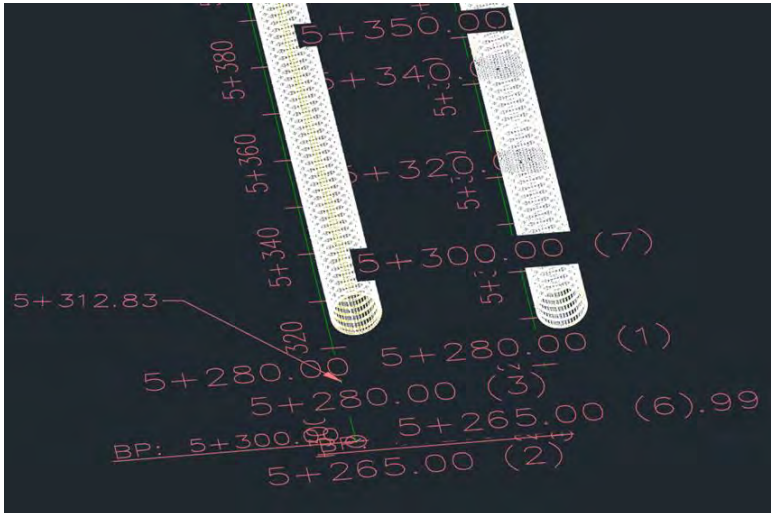


Figure 67: combined model: alignment data, placement of the Assembly each 1.5m and sweep of the Assembly along the alignments

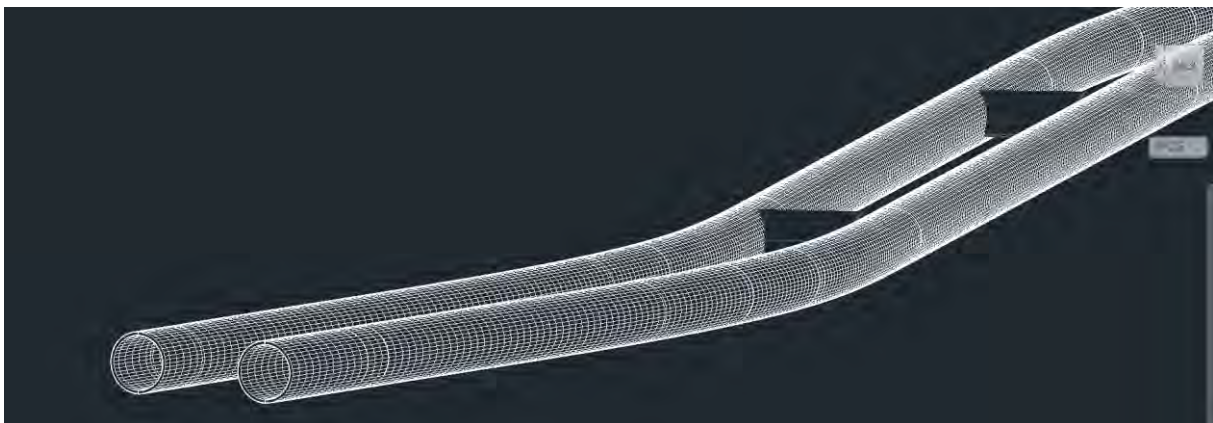


Figure 68: Geometry Model (cross passages included)

The evaluation tool is applied on the corresponding IFC4x3 files and the outcomes are investigated in the following.

Some of the following suggestions exceed the planned usage of the ÜAG IFC models. The available structural analysis discipline tunnel model is not supposed to fulfil all of these requirements because it is not actively used for the planning and construction process. Nevertheless, it is beneficial to envision possible improvements and extensions of the model to apply this knowledge in future projects. As the bSI IfcTunnel extension is not published yet, the basis for metro projects is not yet clearly defined (bSI - IFC specification Database). So the following suggestions are related to the requirements report of the tunnel project Phase 1 (Michel Rives et al., 2020) and based on the recommendation of the IFC Rail Team.

5.2 Results of Applying IFC4x3

5.2.1 Hierarchic Structure

The extension of the schema by the hierarchical components of IfcFacility delivers the basis for more flexible containers. The IfcBuildingStorey entity has intended a vertical decomposition of high-raised structures. By adding IfcFacility and its subcomponents to the schema, the spatial containers can be aggregated in a more flexible fashion and allow a finer breakdown structure in IFC models.

The IFC Rail Project – Requirement analysis report gives solutions for the hierarchical aggregation structure of projects. In general, the IFC Rail team suggests a vertical and lateral breakdown structure, as there are no clear concepts of breaking down a railway project across all domains in the longitudinal context. The vertical breakdown structure is visualised in [Figure 69](#). The profile view is further decomposed into super structure, lineside structure, track structure and sub structure. (IFC Rail Project, 2019)

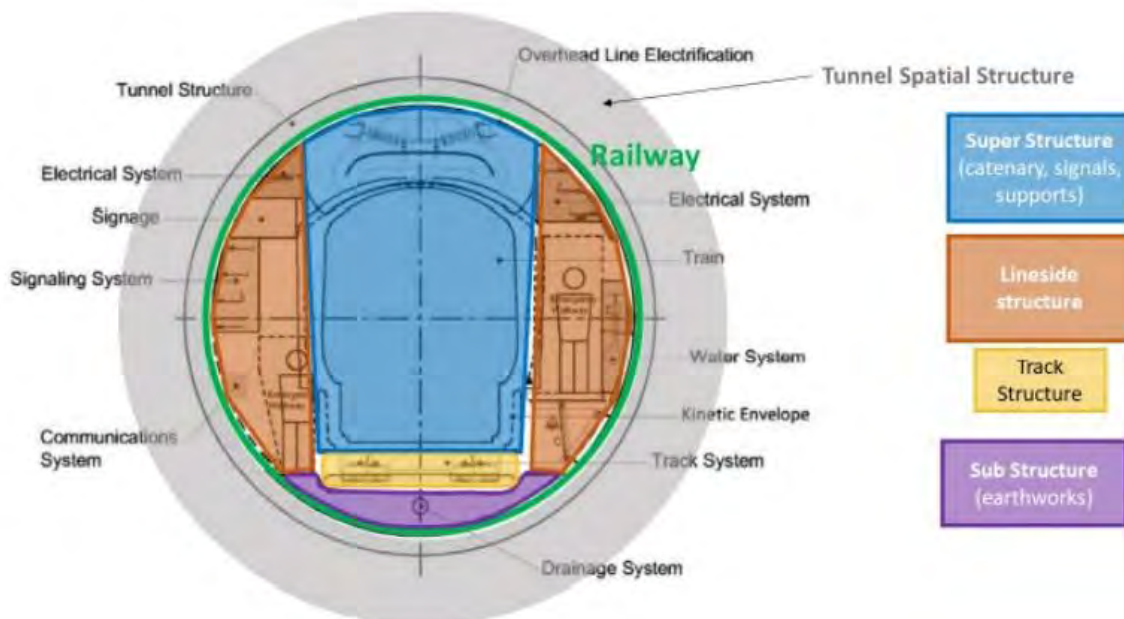


Figure 69: vertical spatial breakdown structure IFC Rail connected to IFC Tunnel domain (IFC Rail Project, 2019)

In the second stage, the rail team suggests a domain-specific longitudinal spatial structure. For example, the track domain structure could be split up into turnouts and straight tracks or the structure of the railway energy facilities domain could be split up into tension sections. (IFC Rail Project, 2019)

These precise suggestions for a domain specific breakdown are not very suitable for metro projects, as there are not many turnouts and the tunnel is configured to also fit the requirements of the power supply. However, these underlying ideas suggested by the IFC Rail Team can be transferred to the metro tunnel context. Possibly, a spatial breakdown structure following the longitudinal tunnel layout structure would be reasonable within this metro project. The tunnels can be split up into tunnel sections at a medium level. By separating the plain line structures from the intersections with cross passages, it may be possible to target the complex intersection tunnel structure independently. This sectioning could be beneficial, as these complex parts could be treated separately in further planning steps, for example, by implementing a higher Level of Detail (LoD) in this area.

The IFC Tunnel team (Michel Rives et al., 2020) delivers three different options to bring the two domains of railways and tunnels in a railway tunnel in a hierarchical order. Either both elements are equivalent, or the tunnel could be contained in the railway structure or vice versa. As this project is a metro tunnel project, the superordinate facility should be the tunnel.

Since only parts of the project are remodeled in Civil3D, the outcomes of the evaluation tool regarding the hierarchy are limited. So, the following hierarchical structure sketches a proposed spatial breakdown of the model that addresses all of the issues discussed above. The structure is also based on the sample projects included in the IFC4x3 documentation.

A. IfcProject (Metro Line)

A.a. IfcSite (Section 06)

A.a.1. IfcBuilding (Atasehir Station)

A.a.1.1. IfcBuildingStorey (e.g. R.Ü.K 0,00)

A.a.2. IfcFacility (IfcTunnel not available yet)

A.a.2.1. IfcFacilityPart Tunnel 1, Section 1

IfcRelContainedInSpatialStructure (Relating: IfcRail)

A.a.2.1.1. IfcSpace

- Ring Segment

A.a.2.1.2. IfcSpace

- Track structure Component 1 (e.g. sleeper...)

A.a.2.1.2. IfcSpace

- Superstructure Component 1 (Cable)

A.a.2.2. IfcFacilityPart Tunnel 2, Section 1

IfcRelContainedInSpatialStructure (Relating: IfcRail)

A.a.2.1.1. IfcSpace

- Ring Segments

A.a.2.1.2. IfcSpace

- Track structure Component 1 (e.g. sleeper...)

A.a.2.1.2. IfcSpace

- Superstructure Component 1 (Cable)

A.a.2.3. IfcFacilityPart Tunnel 1, Intersection Crossway 1

IfcRelContainedInSpatialStructure (Relating: IfcRail)

A.a.2.4. IfcFacilityPart Tunnel 2, Intersection Crossway 1

IfcRelContainedInSpatialStructure (Relating: IfcRail)

A.a.2.5. IfcFacilityPart (crossway 1)

Type = crossway

A.a.2.3.1. IfcSpace (Intersection Tunnel 1 crossway 1)

A.a.2.3.2. IfcSpace (Crossway)

A.a.2.3.3. IfcSpace (Intersection Tunnel 2 Crossway 1)

A.a.2.6. IfcFacilityPart (Tunnel 1, Section 2)

A.a.2.7. IfcFacilityPart (Tunnel 2, Section 2)

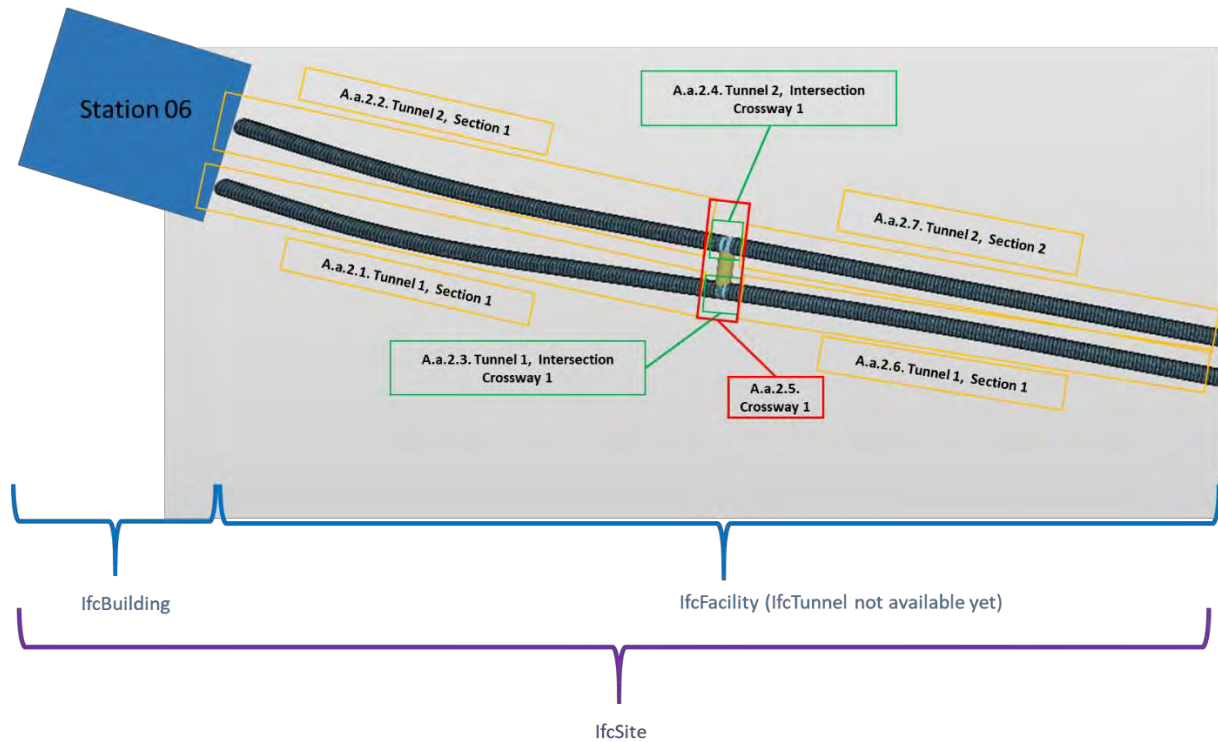


Figure 70: visualisation of the proposed longitudinal spatial breakdown structure of the Atasehir metro project

5.2.2 Semantics

By extending the schema with template-based property management in IFC4x3 the ability of user- or project-specific information delivery is implemented. The application of user-defined properties increases the quality of a model by meeting project-specific requirements (Esser & Borrmann, 2019). The outcomes of the clash detection of the ÜAG models support the fact that an extension in the semantic description would increase the model's quality. For instance, defining rule sets within the clash detection would be more fine-grained, if the elements had more properties describing them.

The resulting four solid components of the sample model represented by the ODA viewer can be seen in [Figure 71](#). To generate a sample output, a user-defined corridor property set is implemented in the model.

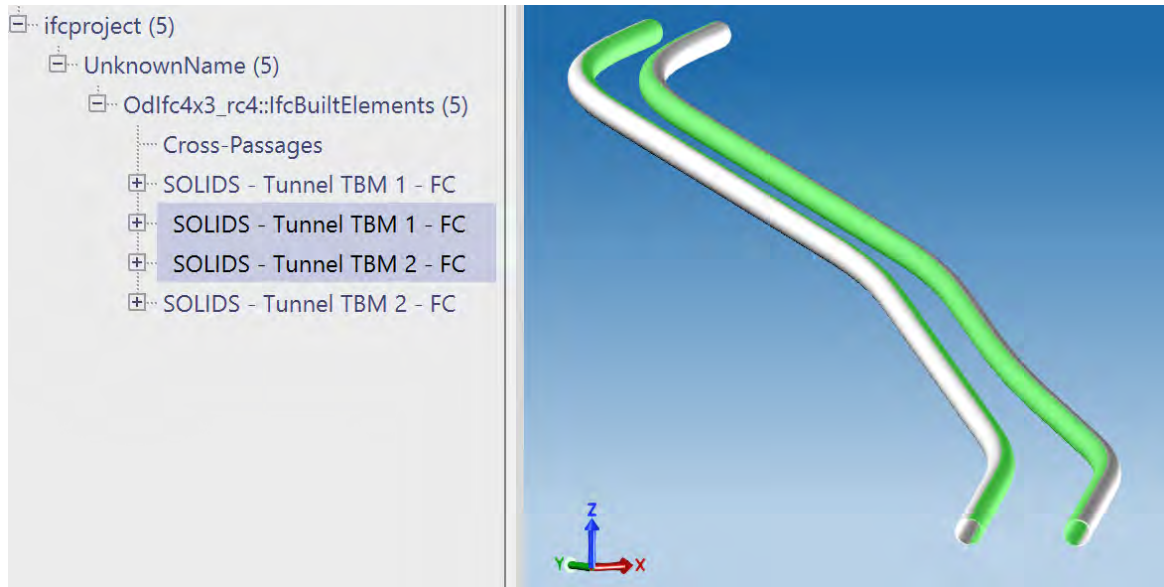


Figure 71: Remodeled sample file Geometry Model

During the output process, seven property sets are assigned to each of the two extruded tunnels, including one user-defined property set given the measurements of the segments. For the cross sections, the IFC file includes five different property sets. This is similar to the IFC2x3 output, where each tunnel segment is described by four property sets.

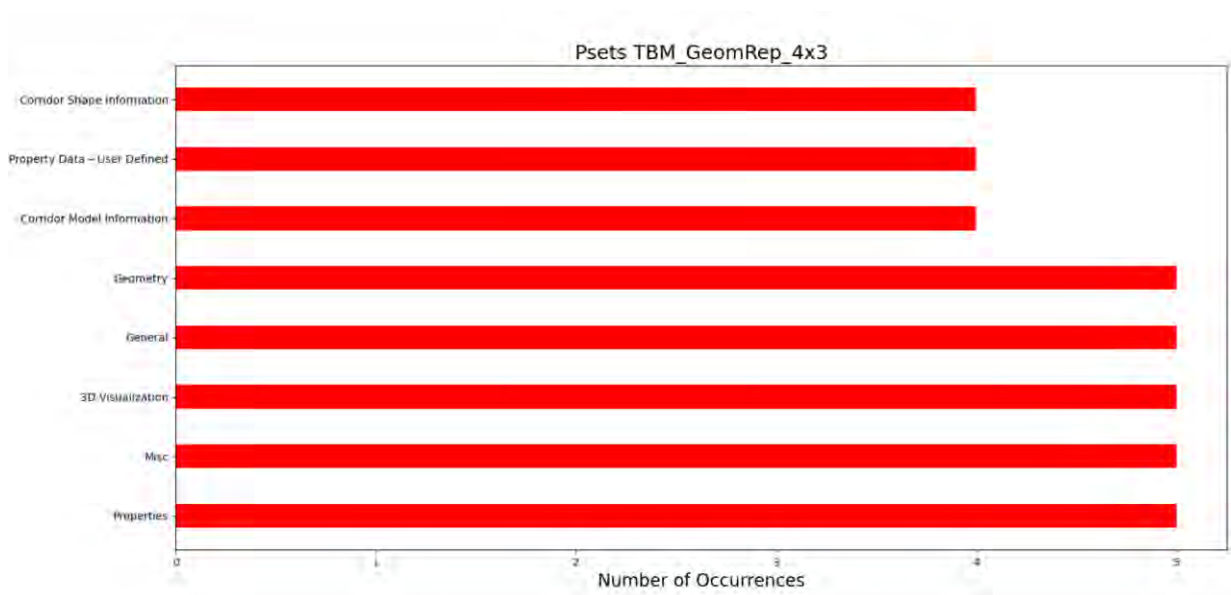


Figure 72: Property Set management within the exported IFC4x3 file

However, the number of single values assigned to each property set increases. This number goes up to 28 values for one property set, while the number of values assigned is at most five in the IFC2x3 model. The property sets of the Civil3D IFC4x3 output are

named “properties”, “misc”, “3D visualisation”, “general”, “corridor model information”, “corridor data user defined”, “corridor shape information” and “geometry” (Figure 72). In contrast to the IFC2x3 models it is noticeable that the property sets include data for describing the geometries, such as “ReceivesShadows”, “IsPlanar” or “Visible”. Additionally, information about the start and end stationing, volume and the name of the baseline of the extrusion is given. This makes it possible to distinguish to which tunnel the segment belongs to. The sample output shows, that only through the default export settings within Autodesk Civil 3D, the semantic information delivery is improved.

bSI IFC Rail Team implemented 156 new predefined property and quantity sets for the rail domain in the schema, which are updated in the buildingSMART Data Dictionary (bSDD) (IFC Rail Team, 2022). No tunnel domain-specific property sets have yet been published by the IFC tunnel team. The rail-specific properties could be used for a more precise description of objects. For example, the `IfcSlab` representing the railway track could be set as the predefined type: `TRACKSLAB`. So, the property set of `Slab-TypeTrackSlab` can be applied to implement the technical standards of the track and `Pset_CessBetweenRails` can be assigned to specify the highest permissible load capacity or its usage purpose. `IfcTrackElements` could be assigned to be of the predefined type `SLEEPER`. Then `Pset_TrackElementOccurrenceSleeper` and `Pset_TrackElementTypeSleeper` can be applied to have clear information about fastening types between sleeper and rail, sleeper types, corresponding technical standards or the status of contamination of sleepers.

These examples form a small selection of the newly implemented options for describing semantics. As can be seen, there are several options to describe the details of the project components. The basic IFC4x3 output of the redesigned tunnel model shows that geometric- and baseline-specific data have been added to the automatically inserted properties compared to the IFC2x3 output. Implementing user-defined properties is straightforward and does not cause problems in the export process.

5.2.3 Placement

The Civil3D export in IFC2x3 of the alignment data produces an IFC file based on `IfcCartesianPoints` and `IfcPolyLoops`. This data is not a reasonable basis for further modeling as it omits stationing data. The IFC4x3 file is structured according to the new alignment concepts explained in chapter 3.1.4. It is nested in a horizontal and vertical

alignment. Each of these alignments is decomposed again in a nested way in several segments of line, clothoid or circular arc. The resulting curve segments compose a shape representation. In the case of the horizontal alignment, the shape representation is an `IfcCompositeCurve`; for the vertical alignment, it is an `IfcGradientCurve`. The output of the evaluation tool concerning the alignment can be seen in the attachment. It is visualised in [Figure 73](#). The lower pair of alignments represents the horizontal alignment, the other pair the resulting alignment in 3D space.

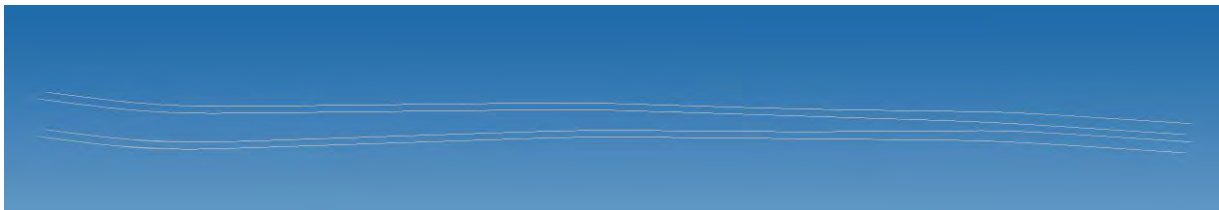


Figure 73: Alignments of the two tunnel axis after IFC4x3 export

Additionally, the alignment acts as linear reference system. As it can be seen in the property set ([Listing 5](#)), the assembly “Tunnel Segment” is extruded along the alignment from a `StartStation` to an `EndStation`. These start and end stations are instantiated through `IfcReferent`. This is a powerful benefit in comparison to the files in IFC2x3, where the extrusion process is not dependent on alignment data and is not recognisable within the property sets.

Corridor Shape Information:

```
#600= IFCPROPERTYSET('0qfnvcdA5FKRbTcTeKEzQn',$, 'Corridor Shape Information', $(#602,#603,#604,#605,#606,#607));
#602= IFCPROPERTYSINGLEVALUE('CodeName', $, IFCLABEL('FC'), $);
#603= IFCPROPERTYSINGLEVALUE('Side', $, IFCLABEL('No'), $);
#604= IFCPROPERTYSINGLEVALUE('AssemblyName', $, IFCLABEL('Tunnel Segment'), $);
#605= IFCPROPERTYSINGLEVALUE('AssemblyStartStation', $, IFCLABEL('5+265.00m'), $);
#606= IFCPROPERTYSINGLEVALUE('AssemblyEndStation', $, IFCLABEL('6+367.00m'), $);
#607= IFCPROPERTYSINGLEVALUE('Volume', $, IFCLABEL('3106.01130581658'), $);
```

Listing 5: Property Set of an implemented corridor (IFC4x3)

Within IFC4x3 it is possible to place objects relative to an axis. This could be beneficial to meet the suggested method of the IFC Tunnel team to represent the tunnel segments of a TBM tunnel only once. This segment is the basis to instantiate the other segments through mapped items, place and rotate them at the corresponding positions. (Michel Rives et al., 2020)

5.2.4 Geometry

A fundamental question is, whether implicit or explicit geometries should be preferred within the IFC export. The IFC Rail Team (IFC Rail Project, 2019) states that editable geometric representations are required for specific use cases such as Railway Design Modeling. This is the reason, why the parametric representation resources should meet the requirements of editable alignment modeling within IFC4x3. The IFC Tunnel development team recommends using explicit geometry representation methods for TBM tunnel segments in the first place. The procedural geometry interpretation capabilities by IFC seem to be “too-prone to errors and misinterpretations” (Michel Rives et al., 2020).

The analysis of the tunnel model in IFC2x3 shows that it has a larger share of implicit geometry representations in comparison to the station models, which leads to misinterpretations within the cross passage areas and causes the errors in visualisation. Except for one intersection, which is represented in an explicit way, all others are displayed incorrectly. This example supports this proposed method of Michel Rives et al. (2020) to adhere to explicit geometry.

The exported sample file of the geometry model delivers the following results in the field of geometric representation:

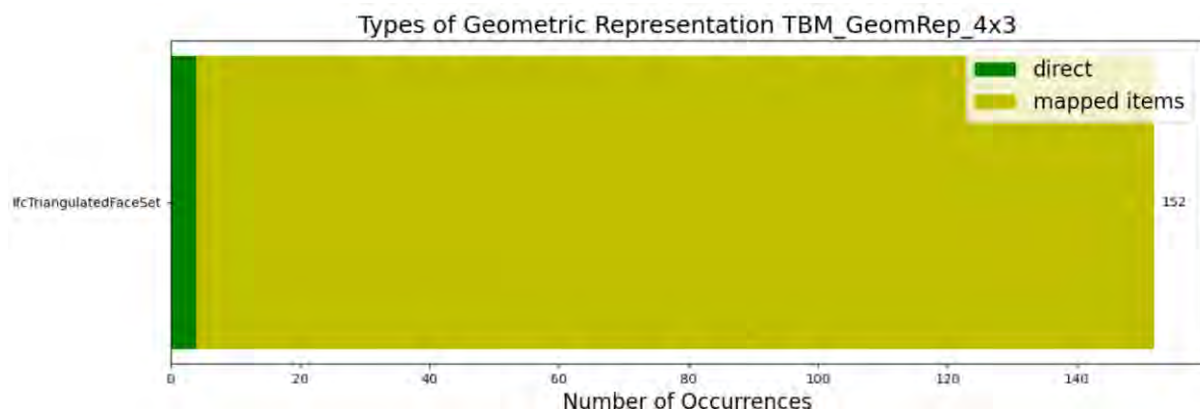


Figure 74: Bar plot evaluation tool Ev9 applied on the geometric model IFC4x3 (solids are only copies of the extruded solids)

Even though the 4 solids (green part of the bar as direct representations in [Figure 74](#)) are produced through sweeping along an alignment, they have been converted to explicit geometries and are represented through `IfcTriangulatedFaceSets`. The cross passages, which are implemented as xref in the model, are represented as mapped item,

which references 148 explicit geometries. These are exported as `IfcTriangulatedFaceSet` as well.

As analysed in chapter 3.1.4 and the literature, highly relevant geometric resources are added in the resource layer within IFC4x3, such as for instance the segment alignments, linear placement or linear extrusion (Stefan Jaud et al., 2020; bSI - IFC4x3 Documentation, 2022). This enables the basis of a hybrid approach composed of implicit and explicit representation that could meet the requirements of all use cases. A detailed description of the geometry will be delivered by explicit representation if the procedural process is complex and error prone for other software. Semantic information about the procedural process can be attached to the object, that it is available for use cases, which for instance requires changes to the geometries. (Michel Rives et al., 2020)

The analysis of the IFC4x3 export of the remodeled combined model describes exactly the hybrid approach (*Listing 6*). The `IfcBuiltElementFC` described in the section of the tool output file is part of the extruded solids. It has two representation sub contexts. The first sub context is the Body representation with the implicit approach (yellow). The second representation sub context is called “Body-Fallback” and is automatically implemented by Civil 3D. This sample section shows that Autodesk Civil 3D supports the hybrid approach for this specific case.

```
IfcBuiltElementFC is represented by:
element has 2 representation contexts
  IfcShapeRepresentation
  the corresponding subcontext is: Body
  type of geometry is a: IfcSectionedSolidHorizontal
  problems occurred while delivering further information
  IfcShapeRepresentation
  the corresponding subcontext is: Body-Fallback
  type of geometry is a: IfcPolygonalFaceSet
{'id': 5575, 'type': 'IfcPolygonalFaceSet', 'Coordinates': #5574=IfcCartesianPointList3D(((
18.50713), (-255.65849, -493.28443, 18.87516), (-255.644, -493.29528, 19.25162), (-255.66934, -493.2
4.50449, -492.27471, 19.14964), (-254.52745, -492.25752, 18.77297), (-254.58957, -492.21097, 18.3870
2, 19.62673), (-254.83384, -492.02797, 19.99084), (-254.93302, -491.95367, 20.33521), (-255.06285, -4
253.79451, -490.93236, 18.00123), (-253.94208, -490.8218, 17.62605), (-254.13176, -490.6797, 17.2727
```

Listing 6: Hybrid approach including explicit Body-Fallback sub context (Combined Model: solids have been extruded in this model)

Considering the proposals from bSI and the findings of the analysis, the geometric representation of the TBM tunnel model could be implemented as follows:

Implicit geometries are utilised to describe the tunnel sections between the intersections, as they do not form a complex procedural process at this planning stage. For the

more complex intersections, explicit geometries are used and the procedural process is attached as semantics to the model. Accordingly, the geometry is editable, when changes are necessary, for instance implementing cable carriers in the cross passages in the later planning steps.

The visualisation of the IFC model representing the scenario “Tunnel segment placed along the alignment in a frequency of 1.5m” was not able to be represented in the viewers. Even though, it is exported by the hybrid approach including the explicit representation sub context “Body-Fallback”. The evaluation tool detects problems accessing the type of the representation item. The placement frequency is set to 1.5m through the definition of `IfcPointByDistanceExpression` in the IFC file ([Listing 7](#)). This scenario seems to cause problems, but further analysis of this specific export problem exceeds the scope of this work.

```
#1789= IFCROADPART('1REyNI9HP69fVZMr$Pk73k',,$,'RG - Tunnel Segment - (1)',,$,'BaselineRegion'
#1790= IFCRELAGGREGATES('1bWsl8HjmZ2hJKYQL3Wxv3',,$,$,$,#1786, (#1789));
#1791= IFCPOINTBYDISTANCEEXPRESSION(IFCNONNEGATIVELENGTHMEASURE(1035.0),,$,$,$,#331);
#1792= IFCAXIS2PLACEMENTLINEAR(#1791,$,$);
#1793= IFCLINEARPLACEMENT($,#1792,$);
#1794= IFCREFERENT('3xASanOTz3kRZXXCnOlgnK',,$,'6+300.00',,$,$,#1793,$, .STATION.);
#1795= IFCRELPOSITIONS('3m6owehJ99Ah2n$HvRnXn',,$,$,$,#1794, (#1789));
#1796= IFCPOINTBYDISTANCEEXPRESSION(IFCNONNEGATIVELENGTHMEASURE(0.0),,$,$,$,#331);
#1797= IFCAXIS2PLACEMENTLINEAR(#1796,#1758,$);
#1798= IFCPOINTBYDISTANCEEXPRESSION(IFCNONNEGATIVELENGTHMEASURE(1.5),,$,$,$,#331);
#1799= IFCAXIS2PLACEMENTLINEAR(#1798,#1758,$);
```

Listing 7: Section of the “placement along axis” IFC file

5.3 Discussion of Results

The evaluation tool provides the data packages, which are accessed through concept templates. Concept templates are part of the technical implementation of use cases. The investigation of the data packages delivered through the evaluation tool within IFC4x3 files leads to the following results:

The spatial breakdown structure of a model is improved within IFC4x3. Through finer decomposition options and more flexibility in lateral and vertical directions, use cases such as “derivation of planning documents” can be delivered in increased granularity. Examples are a power supply plan representing the super structure only in longitudinal direction or floor plans of the cross passages only.

By enabling the alignment-based reference system, many infrastructure-related features are improved. Planning documents, such as cross section drafts can be created at stations along the axis in a specific frequency. Further, elements can be swept along

or next to an alignment within a defined offset. Combined with the hybrid approach in geometry representation, it facilitates a flexible method to represent earthworks along a track or construction progress monitoring.

According to the analysis, the IFC4x3 schema establishes an enriched basis to include semantics in the model. Use cases like “dimensioning and verifications” may get very advanced by providing a solid data basis including, for instance, fastening types of sleepers or other track side environmental information in the model. Since these inputs vary for each project due to its components and boundary conditions, meaningful semantics cannot be automatically implemented in the model. IFC4x3 entities such as `IfcProjectLibrary` or the property set templates deliver options for strong semantics within a model. Thus, to enhance the quality of a model by increasing the semantic information delivery, several features of the IFC4x3 schema should be applied: (1) Using appropriate predefined property sets and standards included in the bSDD, (2) deciding on additional user- or project-specific information and (3) implementing them through user-defined property set templates.

To sum it up, the features added within IFC4x3 form a technical implementation basis to fulfil numerous use cases in an enhanced way. Many of the infrastructure-related requirements are now part of the schema and thus form a solid basis to perform the implementation process.

However, the extension of the schema leads to an increase in complexity. Therefore, the methodology is expanded by a rising number of opportunities for each step. Consequently, new questions come up, for example about a suitable granularity for the breakdown structure with the extension of many spatial structure elements - `IfcFacility`, `IfcFacilityPart` and `IfcSpace`. Another issue might be the selection of the most suitable geometric representation for the corresponding task, when several geometries are available in the model for one element. These questions have increased in complexity, which demands a high level of guidance through standards, advanced automation in the software solutions and expertise of the people involved in the process. With this ongoing process of schema enrichment, the development towards an automated controlled exchange process, such as an IDS, is a reasonable long-term goal.

6 Conclusion

6.1 Summary

The results, obtained in this work compare the capabilities of IFC2x3 and IFC4x3 concerning their contribution to defined use cases. It addresses the research question whether the future ISO standard of the IFC4x3 schema provides a simple and effective basis for the full process implementation. To develop an objective evaluation framework, several steps have been taken. In the first step, a literature review was conducted outlining the relation of the BIM Use Cases being connected to the IDM/MVD method, which is technically implemented in the BIM process through concept templates. To gain deeper understanding, the documentations of the schemes were compared concerning their definitions related to infrastructure assets. Based on the main differences in the definition of the schemes, an evaluation tool was created, that delivers the data packages, which are accessed through the corresponding concept templates. This information builds a solid basis to evaluate real-world models from the metro line project “Ümraniye-Ataşehir-Göztepe” in Istanbul, available in IFC2x3, to their capability to represent and store infrastructure-related information.

Outcomes unveiled different problematic aspects. The information delivery through the semantics is limited. The geometric representation contains deficiencies. The fields of object placement and hierarchic structure are fully exploited in the model, but insufficient due to limitations in IFC2x3. Through remodeling corresponding aspects in IFC4x3, it was revealed that the object placement is successfully extended by an alignment-based reference system, enabling linear placement. The geometric representation is more reliable through a hybrid approach combining explicit and implicit geometry. The spatial composition structure is suitable for infrastructure projects through an increased flexibility within IFC4x3. In addition, the new IFC schema provides several options to implement a solid semantical basis in the model. Hence, a model represented through IFC4x3 is capable of containing a sound and efficient data basis with a high flexibility in the application of downstream tasks in the BIM process. However, exploiting the full potential of IFC4x3 within a project requires high level of guidance through standards and expertise among users.

6.2 Outlook

BuildingSMART international announced the IfcTunnel extension within the future IFC4x4 release. Predefined property sets corresponding to the tunnel domain will certainly facilitate implementing the semantic basis of metro projects. Additionally, the ÜAG Revit models contain data of process management for scheduling and construction monitoring, such as the completion rate of each element. These aspects are neglected within this work, as the data is not part of the initial IFC files. Accordingly, the capability of the IFC schemes related to 4D and 5D application is beyond the scope of this work. As analysed in the schemes comparison, great changes have been applied in the IFC definitions related to process management. Potential future research could focus on integrating these aspects in the IFC-based workflow and testing the IFC4x3 potential in the corresponding fields.

As the evaluation tool was primarily developed to evaluate the models utilised within this case study, some adjustments may be necessary to adapt it to other features. For instance, the tool was used to analyse the hierarchic structure of a model based on the concept template of “Spatial Decomposition”. So, it is limited to the attribute “IsDecomposedBy” of an element and is not extended to support the ordered decomposition “Nesting” yet.

The scripts developed within the scope of this work, can potentially be further used as part of an automated quality checking process. The quality checking of a model is carried out through different steps, which require data bundles delivered by the evaluation tool. For example, to check certain model data, a listing of all entities is essential for evaluating the selected IFC classes and for geometric checking a list of the relative placement needs to be investigated. These and further data extractions are delivered by the evaluation tool and therefore build an essential basis for automated quality checking. After adapting some internal processes and in combination with either a stand-alone, self-explanatory Graphical User Interface (GUI) or by an embedding into commercial software tools, this can be a further field of application of the to

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Erklärung

Hiermit erkläre ich, dass ich die vorliegende Master-Thesis selbstständig angefertigt habe. Es wurden nur die in der Arbeit ausdrücklich benannten Quellen und Hilfsmittel benutzt. Wörtlich oder sinngemäß übernommenes Gedankengut habe ich als solches kenntlich gemacht.

Ich versichere außerdem, dass die vorliegende Arbeit noch nicht einem anderen Prüfungsverfahren zugrunde gelegen hat.

München, 1. Dezember 2022

Vorname Nachname