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Comparative Analysis of Building Information Modelling (BIM) and RailTopoModel/railML in View of their Application to Operationally Relevant Railway Infrastructure

Project Paper in the Field of Intelligent Transportation Systems

by

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List of Abbreviations

AEC	Architectural, Engineering and Construction
AIM	Asset Information Model
BIM	Building Information Modelling
bsDD	buildingSMART Data Dictionary
bSI	buildingSMART International
BS	British Standard
BSI	British Standards Institution
CAD	Computer-Aided Design
CABR	China Academy of Building Research
CDE	Common Data Environment
ERIM	European Rail Infrastructure Masterplan
ETCS	European Train Control System
GUID	Globally Unique Identifier
IDM	Information Delivery Manual
IFD	International Framework for Dictionaries
IFC	Industry Foundation Classes
IRS	International Railway Solution
PIM	Project Information Model
RINF	Register of Infrastructure
RTM	RailTopoModel
UIC	International Union of Railways
XML	Extensible Markup Language

1 Introduction

BIM is the abbreviation for Building Information Modelling and describes the whole life cycle of a construction project. Based on a 3D model with height, width and depth data of components, the two "dimensions" of time and costs are added. This finally leads to a 5D model that shall revolutionise the way of constructing. It aims at making construction projects more economic, sustainable and punctual. Some people even speak of an 6D model, adding the dimension of life-cycle facility management.

Originally, BIM derived from the area of building construction but is currently on the rise in many other fields. The German Federal Ministry of Transport and Digital Infrastructure published a road map for the implementation of BIM in December 2015, which states that BIM will become an integral part of future governmental infrastructure projects. [24] The scope of application of BIM is huge, nevertheless this paper only focusses on the modelling of railway infrastructure.

In the year of 2002 an initiative - railML.org - started to develop a standardized data exchange format – railML – tailored to the specific needs of the railway industry. In close cooperation with railML.org and Infrastructure Managers from around Europe, the International Union of Railways (UIC) developed a systemic model for the description of topology-based infrastructure of railways: RailTopoModel (RTM)

At this point, one may ask if RTM and the BIM model have similarities, maybe even reassemble each other; or are they totally different? Which data is necessary or rather which data can be processed by the models correctly? Which formats are used for the exchange of data? On which basic structures do the models build upon?

The following pages aim at analysing and comparing RTM and BIM in view of their application to operationally relevant railway infrastructure concluding in an assessment of potential future collaboration of RTM/railML and BIM.

2 Building Information Modelling

2.1 BIM in the World

2.1.1 The Beginnings

The beginnings of BIM can be dated back to the middle of the 20th century. Various opinions about who actually started to think and document about something which could be referred to as the earliest stage of BIM, exist. Some say CHARLES M. "CHUCK" EASTMAN´S "Building Description System" published in the year of 1975 in the AIA Journal is the earliest approach to BIM. Others note that DOUGLAS C. ENGLEBART already stated a BIM similar vision in his paper "Augmenting Human Intellect" in the year of 1962. [23, 39]

No matter who and when BIM was firstly mentioned the further development in the late 1900´s mostly took place in Europe – most notably in Finland and the United Kingdom -, and in the United States of America. Charles Eastman, Professor in the Colleges of Architecture & Computing of the Georgia Institute of Technology, is a pioneer in the field of BIM and AEC CAD programmes. Since the middle of the 1970´s he has been working on the definition of Building Information Modelling. As cited above he published the "Building Description System" in the year of 1975, followed by "Building Product Models" in 1999, which finally led to what is today known as BIM. Some people refer to him as the "father of BIM". [23]

In the following four randomly chosen countries will be portraited for the analysis of national BIM development. The selection does not state anything about the status of BIM development or international relevance of these or other countries. BIM is a matter which has reached nearly every country in the world, as digitalisation is a worldwide phenomenon of the current decade

2.1.2 BIM in the United Kingdom

Today the United Kingdom is one of the leading nations concerning the development and implementation of BIM. They are ambitious to keep this status or even strengthen their position in the field of BIM implementation. A government/industry BIM programme aiming at adopting BIM technology in the public and private sector was initiated in July 2011 and settled down its goals in the BIS BIM Strategy and the Government Construction Strategy. The main drivers for BIM in the UK are the reduction of asset costs and the achievement of greater operational efficiency, the facilitation of greater efficiency and effectiveness of construction supply chains, and the assistance in the creation of a forward-thinking sector on which they can base their growth ambitions. [28]

The Building Information Modelling Task Group is an official body of the Cabinet Office, funded by the UK Government. It was originated to achieve the objectives of the Government Construction Strategy in spring 2011. Core component of the BIM chapter of the Government

Construction Strategy is to support the industry in the process of developing standards, enabling all members of the supply chain to work efficiently through Building Information Modelling. [19]

In order to achieve this goal, BIM Maturity Levels – also known as Bew-Richards Maturity Model - were introduced in a Strategy Paper for the Government Construction Client Group from the BIM Industry Working Group in March, 2011. The paper indicates four different levels, starting with the basic Level 0. As illustrated below, Level 0 refers to unmanaged 2D CAD drawings with (electronic) paper data exchange. This is the most conventional way of exchanging data. Level 1 includes managed 2D or 3D CAD referring to the BSI 1192:2007 standard. The BSI 1192 standard will be explained in more detail later. Level 1 shall possibly contain first standardised data structures and formats to ease an exchange of building data. Level 2, which was set to be achieved by 2016 contains not only geometrical 3D data but also non-geographical project lifecycle data such as costs, allowing to speak of an 4D or 5D model. The data shall be exchanged in a Common Data Environment (CDE) with all participants of a project, which is why Level 2 BIM is also referred to as the "Collaborative BIM". To ensure exchangeability, the BIM Task Group has provided necessary standards, guides, case studies and trainings in seven different standardised guidelines: [10, 26, 34]

- BS 1192:2007: Collaborative production of architectural, engineering and construction information. Code of practice.

- BS 8536-1: Briefing for design and construction. Code of practice for facilities management (Buildings infrastructure)

- BS 8536-2: Briefing for design and construction. Code of practice for asset management (Linear and geographical infrastructure)

- PAS 1192-2:2013: Specification for information management for the capital/delivery phase of construction projects using building information modelling

- PAS 1192-3:2014: Specification for information management for the operational phase of assets using building information modelling

- BS 1192-4:2014: Collaborative production of information. Fulfilling employer's information exchange requirements using COBie. Code of practice

- PAS 1192-5:2015: Specification for security-minded building information modelling, digital built environments and smart asset management

The goal of reaching Level 2 BIM by 4th of April, 2016 was achieved and Level 2 BIM is now a mandatory part of governmental construction projects. Level 3 exceeds Level 2 in the fact that all parties are now working on one single shared model held in a centralized repository. It is also known as "Open BIM" or integrated BIM (iBIM). The UK Government Budget 2016 policy paper published in March 2016 confirms financial support for this project. Level 2 BIM brought a cost reduction for infrastructure projects of round about 20 %, which shall be expanded to

an even higher percentage with BIM Level 3. Furthermore, the United Kingdom´s global leadership in digital construction shall be maintained. [10, 26, 34]
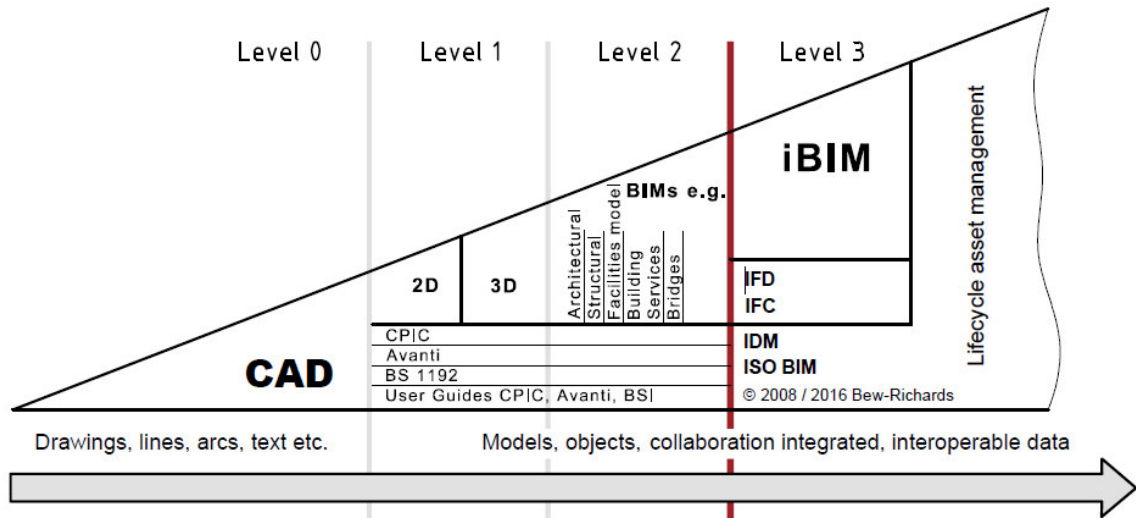
Illustration 2.1: UK BIM Maturity Levels. [10]

Since 2006 the development of BIM in the UK takes place in close collaboration with the British Standards Institution (BSI). The most utilised and distributed standard is the BS 1192:2007 + A2:2016 whereas A2 is referring to an amendment in the year of 2016. The document refers to the ISO (International Organization for Standardisation) 12006-2 Building construction standard. BS 1192:2007 describes the methodology for managing the production, distribution and quality of construction information using a disciplined process for collaboration and a specified naming policy. It is the oldest of the BIM standards [1]. Building up on this document, PAS 1192-2:2013 was published specifying a framework for the phase of the actual design and construction process of projects. As shown in the illustration below, seven levels of model definition were set up for the BIM process of building and infrastructure projects. PAS 1192-2:2013 focuses on the Project Information Model (PIM), the first 6 steps prior to the handover. The Asset Information Model (AIM) which e.g. contains maintenance information that becomes relevant in the subsequent operational phase is addressed in PAS 1192-3:2014. PAS 1192-3:2014 can be applied to any asset management phase of buildings and helps to further understand, predict and manage the assets. [6, 7, 18]
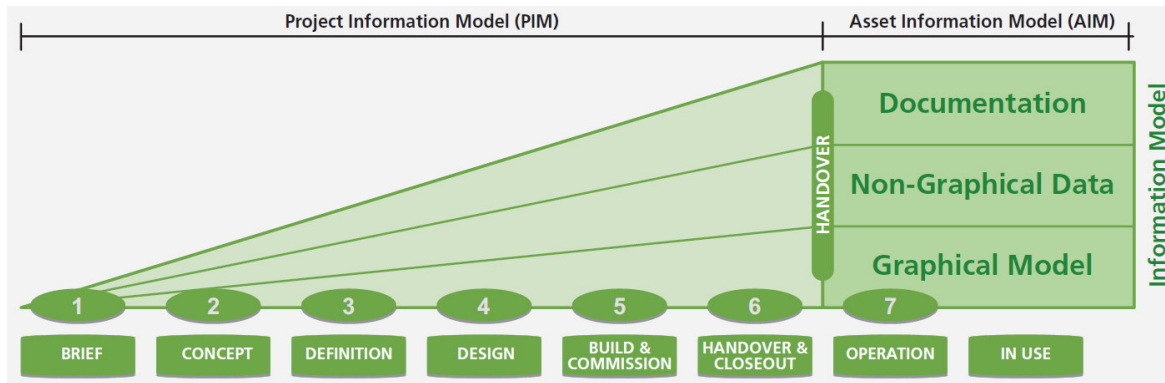
Illustration 2.2: Levels of model definition. [19]

In addition to these three major standards the BSI published further documents describing the process of BIM. One of them is BS 1192-4:2014, which outlines the UK usage of COBie (Construction Operations Building information exchange), an international standard for the description of facility information of both buildings and infrastructure. The exchange format for COBie data is IFC (Industry Foundation Classes), which is explained at a later stage of this paper. A further standard is PAS 1192-5:2015 dealing with cyber security throughout the process of creating a digital BIM model. These standards are the most relevant UK standards, concerning BIM implementation. Due to the extent of this paper this subject is not described further. Nevertheless, it is important to point out at this stage that the UK currently seems to be very ambitious and advanced about BIM.

One of the biggest governmental infrastructure projects currently ongoing in Britain is HS2. HS2 is the acronym for High Speed 2 and refers to a high-speed rail network connecting London to Leeds, Birmingham and Manchester in future. As HS2 is a project of extreme dimensions, delivering on time and on budget is a true challenge. BIM is seen as a central part in achieving this, as it is a centralized environment to collect and exchange data between all participating stakeholders. Furthermore, it contributes to informing the population, especially by construction works effected people, and can influence the social acceptance of the project in a positive way. [8]

2.1.3   BIM in China

Currently China is a very striving country when it comes to BIM implementation. A forecast of Dodge Data & Analysis in the year of 2015 indicates that the number of architects and contractors that will be using BIM for more than 30% of their projects in the next two years will grow in China by 108%. The average global growth rate in this area is 95%. China is amongst the five fastest growing BIM regions, alongside with the UK, South Korea, Australia and Germany. The study also analysed the attitude of non-BIM-users in China and came to the result that 89% of non-users are interested in BIM, only 11% state to have no interest. As the study was based on a fairly small sample of 350 architects and contractors in China, 296 BIM users and 54 non-users, it might not be representative for the entire Chinese building industry but indicates that BIM knowledge and acceptance is already widely-spread. [21]
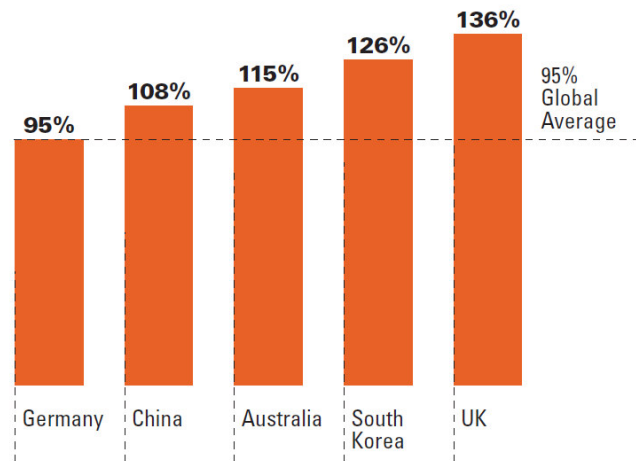
Illustration 2.3: Dodge Data & Analytics, 2015 study results. [21]

As in other parts of the world the Chinese building industry appreciates the following benefits derived from BIM:

- Better design solutions

- reduced errors and omissions in construction documents, as error prone manual work is close to zero

- more client involvement and improved understanding

- reduced rework, etc.

All of these aspects have in common that they reduce workload and improve the transparency of complex building projects, which helps to keep cost low and minimize errors. [21]

In the year of 2012, the China Academy of Building Research (CABR) and several other organisations established the China BIM Union to promote the coordinated development of China´s BIM technology, standards and software. Nevertheless, Chinas government has not yet issued a roadmap for the implementation of BIM that schedules and describes a certain compulsory level of BIM in construction works, as other countries have done. The 12th Five-Year Plan for Development of Construction Industry issued by the Ministry of Housing and Urban-Rural Development of the People´s Republic of China refers to BIM as a key technology for information development in the Outline of Information Development of Construction Industry during 2011-2015. In March 2016, the 13th Five-Year plan has been published. Unfortunately, an English version is not yet publicly available. Therefore, no assessment can be made, what impact BIM will have in the coming five years on the part of Chinese government. Nevertheless, a lot of studies are being undertaken by both the governmental and private

sector. Also, various national BIM standards have been developed and introduced, e.g. The Unified Standard, The BIM Delivery Standard, etc. Interesting is the fact that beside national standards also several cities have begun to develop their own standards. The distribution and implementation of BIM in China seems to be a rather decentralized process. [21]

It is fairly difficult to acquire reliable profound information about the Chinese BIM guidelines and process. This can be justified by the language barrier and the information politic of the Chinese government. Therefore, no further description of the standards is possible at this stage.

China´s construction project "Shanghai Tower", a 632-meter-high prestige building in the heart of Shanghai's financial district Pudong and the second highest building in the world, was completed in summer 2015. BIM played a significant role throughout the design and building phase. "The project complexity would be very difficult to manage successfully with traditional project delivery methods and systems.", says Qing Ge, chief engineer and vice general manager for Shanghai Tower Construction & Development Co., Ltd. A team of three people monitored the impact of BIM on the overall project delivery and concluded that rework costs due to documentation errors or lack of coordination is less than 0.22% of the total project cost and the construction time with 73 months has been about 30% faster compared to extrapolations of more common "smaller" high-rise buildings. BIM shall stay part of the Shanghai Tower in future as it will support facility management and operations. Two further top Chinese infrastructure projects with BIM participation are the construction of the Shanghai Disneyland Resort and the Phoenix Media Centre located in Beijing. [21]

2.1.4 BIM in the United States of America

In comparison to China, BIM is embedded in the United States for a much longer time. Back in 2005, the National BIM Standard-United States Project Committee (NBIMS-US) was established and in 2008 transformed into a council of the buildingSMART alliance®, an alliance created to drive efficiency and eliminate waste in the building industry by developing standards. Yet the beginnings of BIM in the U.S. can even be tracked back to the year of 1992, as the Facility Information Council (FIC) can be understood as the predecessor of the NBIMS-US project committee. NBIMS-US is financially supported by the Charles Pankow Foundation, a non-profit, public benefit and charitable foundation focusing on providing the AEC Industry with a better way to design and build. [25]

In early 2008, the first national BIM standard was released with the "NBIMS Version 1 – Part 1: Overview, Principles, and Methodologies for Public Use". Until today, the standard was improved and significantly expanded, which led to the publication of the NBIMS-US™ V3 in July 2015. Experts from across the U.S. and around the world have had the opportunity to enrich the new BIM standard NBIMS-US™ V3 with their ideas. The NBIMS-US™ V3 can therefore be understood as a joint collaborative standard of the building industry, which in the eyes of the publishers is well suited to be adopted not only by businesses, jurisdictions and federal agencies in the U.S. but also by foreign countries. The predecessor version NBIMS-US™ V2, for

example was already adopted by other countries (e.g. the United Kingdom and South Korea) as a basis for their own national standard. [25, 33]

NBIMS-US™ V3 is a compilation of the most relevant submissions and totals more than 3100 pages of content. Amongst others, the "Construction Operations Building information exchange (COBie) Version 2.4" – already mentioned in the chapter about BIM in the United Kingdom -, the "Level of Development Specification" – an American specification to clarify the content and reliability of BIM at various stages in the development and construction process - , and "OmniClass Tables" - an industry standard jointly developed by organisations from the U.S. and Canada to organize and structure construction information - are part of the document. [5]

The US General Services Administration (GSA) is an independent agency of the United States government and provides workspace for more than 1 million federal civilian workers, oversees the preservation of more than 480 historic buildings, and is in charge of the federal government´s purchase of high-quality low cost goods. They played a determinant role in the establishment of BIM in the U.S., by publishing a 3D-4D BIM programme in 2003 mandating the use of BIM in all their spatial projects in 2007 and releasing various guidelines and standards including the internationally recognized National BIM Standard. [46]

2.1.5 BIM in Germany

In December 2015, Germany´s Federal Ministry of Transport and Digital Infrastructure published the Road Map for Digital Design and Construction. The aim of this road map is to gradually implement BIM in Germany´s constructions projects and with that to not only maintain design and construction as a German core competency in the digital era but also to ensure that big infrastructure projects will be realised in time and on budget. The present road map has been developed by the "planenbauen 4.0 Gesellschaft zur Digitalisierung des Planens, Bauens und Betreibens mbH" on behalf of the Federal Ministry of Transport and Digital Infrastructure.

The road map provides three different steps of implementation. From today until mid-2017, the first phase, also referred to as the preparatory phase, is used to carry out pilot projects, clarify legal issues, set up BIM guidelines, etc. From 2017 on, the second phase will be ongoing until 2020 and is characterised by the application of BIM Level 1 in an increasing number of selected infrastructure projects. By the end of 2020, the process shall be matured to an extent that BIM will be applied on a regular basis to new projects in the entire transport infrastructure construction. BIM Performance Level 1 is specified in detail in the Road Map for Digital Design and Infrastructure. The requirements are described by means of the three subsections data, processes and skills. [36]
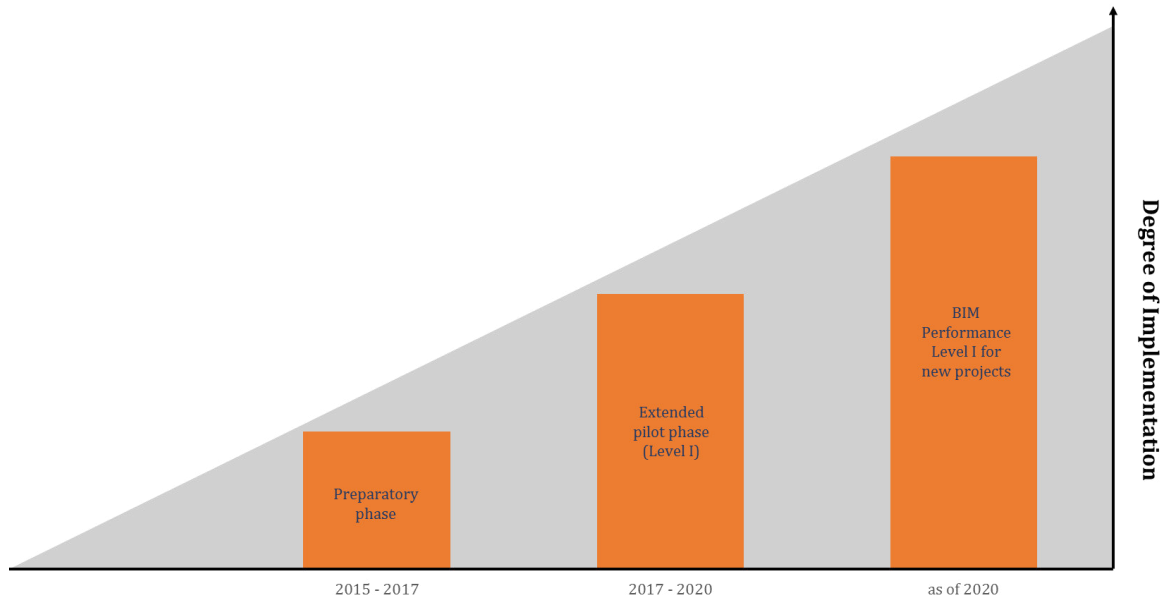
Illustration 2.4: Germany´s road map for BIM implementation. [36]

The pilot phase contains projects in the road sector as well as in the railway sector. The German railway infrastructure manager DB Netz AG will carry out further BIM pilot projects with financial aid from the Federal Ministry of Transport and Digital Infrastructure and aims at a rapid implementation of BIM in the infrastructure sector. For instance, BIM is applied in the railway construction project of the Tunnel Rastatt with very positive feedback and will be an essential part in twelve more railway infrastructure projects of DB Netz AG. Aim of the pilot projects is to test the applicability of BIM and to prove its advantages. [27, 36]

The German Federal Ministry of Transport and Digital Infrastructure has additionally initiated a national expert group in charge of analysing current developments in the standardisation of data exchange for infrastructure BIM-data. This group is dedicated to analysing the Chinese and Korean IFC Rail and Road proposals – which will be further explained in this paper later - and to representing the German interests in this area on international level. [36]

2.1.6 International Collaboration

National BIM work is ongoing everywhere around the world, but as one can derive from the previous chapters every nation is currently developing its own national standards, which may equal developments of other countries in some areas but in general are not congruent. Nevertheless, stakeholders of construction projects are rarely restricted to one specific region or country, which creates the need for a transnational collaboration and standardisation in this area.

The most established and widespread initiative focusing on transnational BIM standardisation is the industry led buildingSMART International. Originally funded in the year of 1995 in the United States, it quickly spread to the German speaking countries, to Great

Britain, France, Scandinavia, Singapore, and many other countries. Today, more than 30 countries are involved in buildingSMART International (bSI) in so called "Chapters". It is registered as a non-profit organisation in the United Kingdom, and aims at fostering the construction of innovative, sustainable and cost-efficient assets by applying modern software solutions with consistent data exchange. [13]

bSI develops and releases Industry Foundation Classes (IFC) specifications, a neutral and open data model to describe, exchange and share information in the building and facility management industry. The current version IFC4, released in March 2013 is accepted as ISO 16739:2013 standard. In the year of 2016, a second addendum IFC4 Add2 was published. IFC is the official data exchange format for OpenBIM, a vendor neutral approach to collaborative design, construction and operation. Furthermore, bSI provides two other, ISO transformed standards: The Information Delivery Manual (IDM), registered as ISO 29481, and the International Framework for Dictionaries (IFD), registered as ISO 12006-3. IDM explains processes and information flow during the whole lifecycle of a facility. IFD is a standard for data dictionaries. The bsDD (buildingSMART Data Dictionary) is based on the IFD standard and a reference library or database of objects and their attributes. [16, 17]
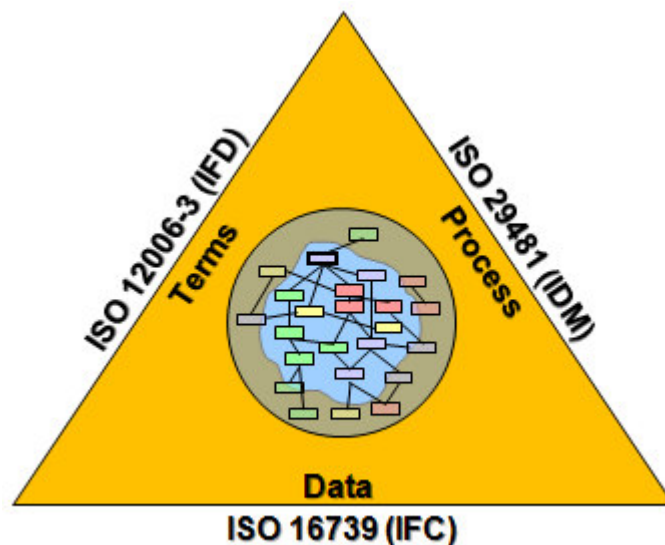
Illustration 2.5: Standards of buildingSMART International. [3]

As the focus of this paper is the analysis of BIM and RailTopoModel in view of their application to operationally relevant railway infrastructure it is important to mention the ongoing work of bSI in the area of infrastructure. The information given above is general information which of course is the foundation for BIM implementation in the infrastructure construction. Nevertheless, the modelling of infrastructure such as bridges, roads, railways, tunnels, etc. have special requirements, which need to be respected. Therefore, bSI has initialised an "Infrastructure Room" consisting of the InfraCom and the Steering Committee, which together form the openInfra initiative. The website of bSI declares that work is ongoing for extensions of IFC. In July 2015, the IFC-Alignment 1.0 was accepted as a buildingSMART Final Standard and quoted as the baseline for further infrastructure projects, such as IFC-Road and IFC-

Bridge. [15]

Of special interest for the railway industry is the publication of the Chinese IFC-Rail in the year of 2015. This is currently available as bSI SPEC (publicly available SPECification), which means that it is not an official international bSI standard but a publication of a national standard in reference to bSI guidelines. The Chinese IFC-Rail standard is of importance to the further development of an IFC extension for railways but is currently characterised by a lot of national influence. bSI proceeded with the appointment of a working group "IFC Infra Overall Architecture" in charge of analysing the Chinese IFC-Rail, the Korean IFC-Road and the French IFC-Bridge and incorporating them as far as possible. The official infrastructure schema extension to IFC 4 shall be issued together with IFC 5 in two to three years. [11, 12]

2.2 Technical Details

In the following, only the open specification of BIM - Industry Foundation Classes (IFC) developed by buildingSMART International - will be analysed, as they represent the international openBIM standard and are therefore vendor independent.

2.2.1 Model Architecture

In March 2013, IFC4 was officially released by bSI. IFC4 is also published as an ISO standard (ISO 16739:2013). It currently is the official IFC version though two Addendums and the extension IFC Alignment have been published since then. For the further analysis of the modelling architecture the IFC4 release will be used.

IFC4 builds up on three ISO standards:

- ISO 10303-11: Industrial automation systems and integration - Product data representation and exchange - Part 11: description methods: The EXPRESS Language Reference Manual

- ISO 10303-21: Industrial automation systems and integration - Product data representation and exchange - Part 21: Implementation methods: Clear text encoding of the exchange structure

- ISO 10303-28: Industrial automation systems and integration - Product data representation and exchange - Part 28: Implementation methods: XML representations of EXPRESS schemas and data, using XML schemas

The first-named standard refers to the description method which in case of IFC is always the EXPRESS language. EXPRESS is a data modelling language that is defined in the EXPRESS Language Reference Manual in two different ways: textually and graphically. With the graphic representation of modelling information, it is possible to show the structure of a model - the relationships, cardinality, entities, and type definitions - illustratively and hence it is more suitable for the human use. The graphical version of EXPRESS is referred to as EXPRESS-G (see

illustration 2.6). The textual definition of EXPRESS (see illustration 2.7) is used for formal verification and as an input for tools. Furthermore, it is possible to model complex constraints, which is an advantage compared to EXPRESS G. Below, you can find two examples illustrating the versions EXPRESS und EXPRESS-G in the context of IFC4. [2, 37]
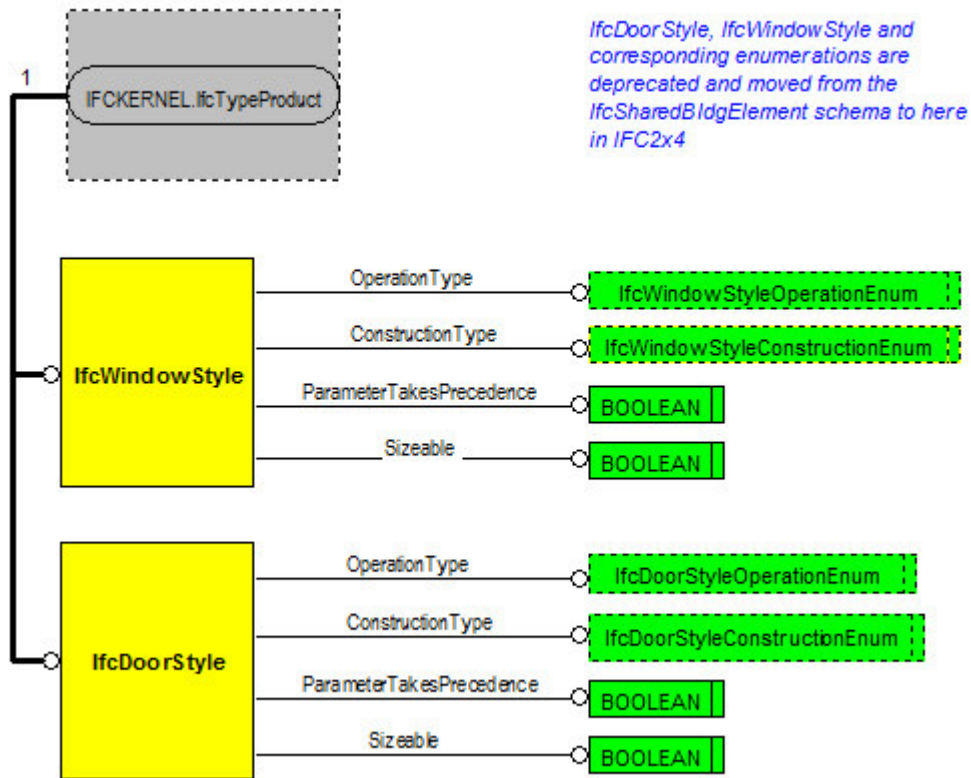
Illustration 2.6: Express-G diagram of Type "IfcWindowStyleConstructionEnum".[3]

```
TYPE IfcWindowStyleConstructionEnum = ENUMERATION OF (
  ALUMINIUM,
  HIGH_GRADE_STEEL,
  STEEL,
  WOOD,
  ALUMINIUM_WOOD,
  PLASTIC,
  OTHER_CONSTRUCTION,
  NOTDEFINED);
END_TYPE;
```

Illustration 2.7: Express Specification of Type "IfcWindowStyleConstructionEnum".[3]

The IFC information model architecture is divided into four different layers: Resource Layer, Core Layer, Interop (interoperability) Layer and Domain Layer. The modular architecture was chosen to ensure that the information model can be adjusted to the dynamic and highly interconnected nature of the information model matter and any changes that must be incorporated consequently. [3, 32]

- The Resource Layer is the lowest layer and includes all individual schemas with resource definitions. The definitions in this layer shall not be used independently of a definition declared at a higher level and do not have a globally unique identifier. Schemas included in this layer are for instance Data Time Resource, Quantity Resource, or Geometry Resource. [3]

- The Core Layer includes core data schemas, which form the most general layer within the IFC schema. In contrast to the Resource Layer, the Core Layer and all superior layers carry a globally unique ID and optionally an owner and historical information. The Kernel schema "IFCKernel", which defines the most abstract part of the specification, and extensions to it – the core extension schemas (e.g. Product Extension, Control Extension) – together form the Core Layer. [3]

- The Interop Layer includes schemas defining entities, which are specific to a general product, process or resource specialization used across several disciplines. Therefore, they are also called shared element data schemas. Definitions in this layer are important for the exchange and sharing of construction information. Examples for Interop Layer schemas are Shared Building Services Elements, Shared Management Elements or Shared Facilities Elements. [3]

- The Domain Layer is the highest layer and includes schemas defining entities that are specializations of products, processes or resources specific to a certain industry discipline. Definitions in this layer are important for the exchange and sharing of general information. For instance, the Architecture Domain, Electrical Domain or Plumbing Fire Protection Domain are part of the Domain Layer. [3]
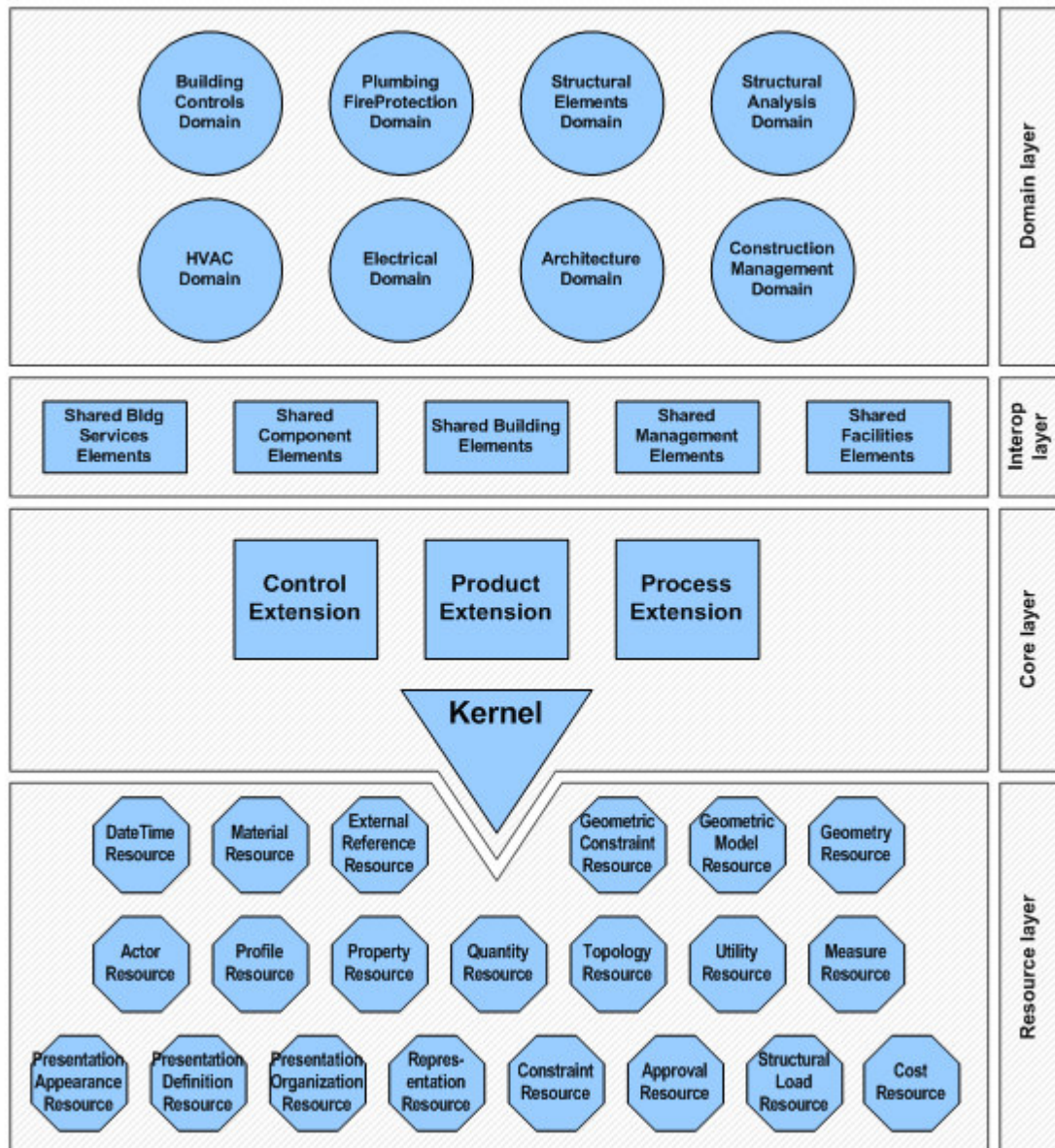
Illustration 2.8: IFC4 architecture with the four different layers. [3]

The IFC architecture model is build up with reference to the software engineering layering principle. This means, that classes may reference other classes from the same (only applies to the Core and Resource Layer) and from higher layers. E.g. a class from the Resource Layer may refer to any class from the Resource, Core, Interop or Domain Layer, whereas a class from Interop Layer may only refer to a class from the Domain Layer. [32]

The detailed documentation of IFC4 is available on `www.buildingsmart-tech.org`. It includes the EXPRESS schema definition as well as alternative XML specifications and reference data.

2.2.2 Data Exchange Format – IFC Rail

The previously analysed IFC4 does not contain any specifications regarding railway infrastructure. However, this is what this paper focuses on. Therefore, the following aims at

outlining the Chinese bSI SPEC IFC Rail publication that exclusively describes railway relevant infrastructure elements.

The Railway BIM Data Standard, which is how the Chinese named their document, builds up on IFC 4x1 and the IFC 4x1 Alignment Extension as well as on four Chinese standards (GB/T), which are also referenced by the ISO norms:

- ISO 10303-21: 2012: Industrial automation systems and integration -- Product data representation and exchange -- Part 21: Implementation methods: Clear text encoding of the exchange structure

- ISO 10303-11: 2004: Industrial automation systems and integration -- Product data representation and exchange -- Part 11: Description methods: The EXPRESS language reference manual

- ISO 10303-1: 1994: Industrial automation systems and integration - Product data representation and exchange - Part 1: Overview and fundamental principles

- ISO 16739: 2013: Industry foundation classes platform

The first two standards are also referenced in the IFC 4 release.

The architecture of the model is based on the previously explained IFC standard, though modified to meet the needs of the railway industry. The Domain Layer is extended by the eight disciplines Alignment, Geology, Subgrade, Bridge, Tunnel, Drainage, Track and Station. In the Interop Layer the module Shared Railway Elements was added. The Product Extension module of the Core Layer was extended by the Ifc Alignment and the necessary entities for the alignment are defined in the Geometry Resource module of the Resource Layer.
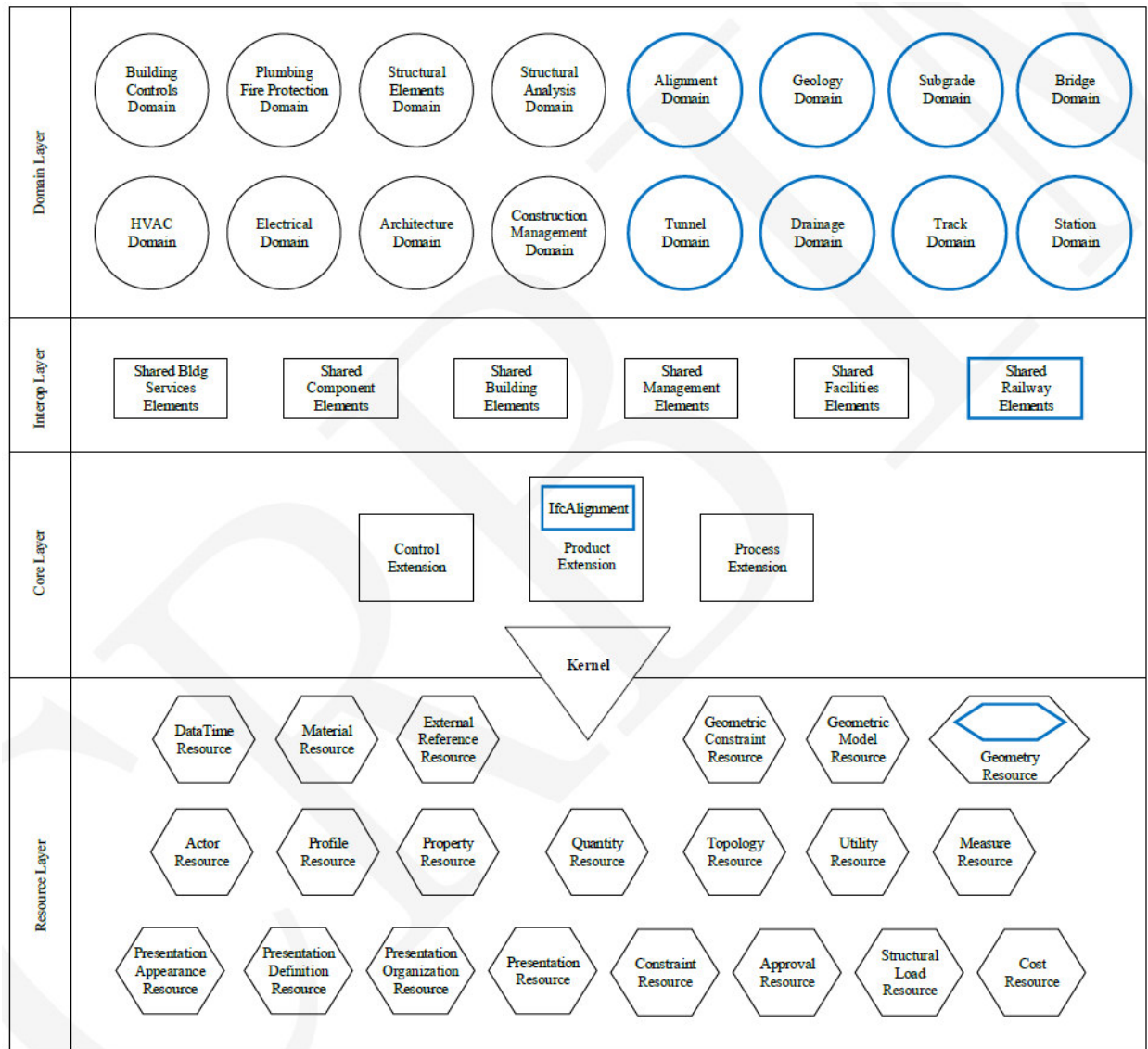
Illustration 2.9: IFC Rail information model architecture. [2]

The document describes the eight-additional railway specific schemas of the Domain Layer and the Shared Railway Elements schema of the Interop Layer. The schemas contain the following information:

- The **Shared Railway Element Schema** is a general schema containing the most important shared Types (e.g. Geo Element Component Type), Spatial Structure Elements (e.g. Railway Structure Element, e.g. Bridge or Tunnel Structure Element), Components (e.g. Railway Element Component) and Property Sets (e.g. Railway Project or Concrete Element General) [2]

- The **Alignment Schema** refers to the buildingSMART IFC4 Alignment extension of 2015. Two changes were made to meet the needs of railway engineering. First the linear reference, which is used to position elements, is changed to a chainage system, and second the transition curve in IFC Rail is defined slightly different than in the Alignment extension. The IfcAlingment describes 3D space by combining 2D horizontal and 2D

vertical construction information in function of the chainage. Both entities IfcAlignment2DHorizontal and IfcAlignment2DVertical are set up of different segments, e.g. IfcLineSegment2D, IfcTransitionCurve2D or IfcAlignment2DVerSegLine. [2]

- The **Geology Schema** consists of the two elements IfcGeologyPart, the supertype of all spatial structure elements in geology engineering, and IfcGeologyElement, the supertype of all physical elements of geology. Soil conditions, geology disasters and drill holes can be further defined and assigned to certain geological sites, e.g. bridge, subgrade, tunnel. [2]

- The **Subgrade Schema** defines the subgrade of railway tracks inter alia by their form, (e.g. embankment, cutting), function (railway, highway subgrade), slope protection (grid frame, hollow brick), and assigns certain functions and a clear starting and end. [2]

- The **Bridge Schema** defines bridges that are part of the railway lines. Amongst others the structural type of the bridge is specified, for instance rigid frame bridge or arch bridge, and technical details, such as slab type, pier segments, arch segments, etc. [2]

- The **Tunnel Schema** not only defines tunnels along the railway line but can also be used for non-railway-related tunnels. Like the Bridge Schema, the Tunnel Schema also specifies tunnels according to predefined types, such as circular tunnel, rectangular tunnel or straight wall and arch crown tunnel. Furthermore, the function of the tunnel (e.g. railway tunnel, highway tunnel, hydraulic tunnel) and further technical details, such as system steel frame types, lining types, portal structure types, etc. are defined. [2]

- The **Drainage Schema** focuses on describing the receipt, storage, distribution and control of the flow of rain and groundwater and the maintenance of collecting vessels near railway infrastructure. It distinguishes between "STORMWATER" which refers to rain water and "DRAINAGE" which refers to ground water. The schema describes the type of drainage (e.g. gutter, catch water ditch) and the location (e.g. near cutting, on slide slope). [2]

- The **Track Schema** describes physical elements of tracks (e.g. sleeper type, slab type, isolation layer type), the function of the track (e.g. main track, connecting line, freight track), clear start and end points, components of tracks (e.g. strengthening equipment, track rail joints) and element assemblies of tracks (e.g. ballast bed, track panel). [2]

- The **Station Schema** defines railway terminals and stations and their components. Amongst others, the terminal type (e.g. linear terminal, combined terminal, one station terminal), terminal feature type (e.g. network terminal, regional terminal, local terminal), station type (e.g. intermediate station, district station), station feature type (e.g. passenger station, freight station), signal type (e.g. starting signal, shunting signal),

and car stopper type (e.g. fixed stopper, slide stopper) are defined. [2]

In general, all schemas are structured by the definition of the schema, followed by the type definitions, entity definitions and finally the property set definition. The bSI SPEC Rail defines an entity as a "class of information defined by common attributes and constraints" [2], schema as "the definition of the structure to organize data for storage, exchange and sharing, using a formal language" [2] and property set as a "unit of information within an entity, defined by a particular type or reference to a particular entity" [2]. Notable is the fact, that the bSI SPEC Rail only uses EXPRESS and EXPRESS-G specifications and no XML specification as the IFC4 release does. The bSI SPEC Rail is available for download on `www.buildingsmart.org`. [2]

2.3 Assessment

2.3.1 Advantages

BIM offers a great variety of advantages for the building industry. As all stakeholders work together on one shared model, less need arises to rework or duplicate drawings for the different requirements of the building industry. The collaboration and communication can be improved significantly as all involved parties have access to the CDE (Common Data Environment) and therefore to as-built documentation. More precise time and cost schedules can be set up as time and costs can be unravelled to the smallest components of a building project whilst obtaining an overview over the whole project. Furthermore, the maintenance and lifecycle management after the construction phase is simplified as detailed information of the components is available in the information model. [20]

All of these aspects lead to a faster delivery of assets and to a reduction of costs and can have a significant positive impact on the complex construction, maintenance and demolition of railway infrastructure. [20]

2.3.2 Disadvantages

As BIM is a relatively new innovation experience and expert knowledge in this area is still rare, the process of implementation might be lengthy and complex. Furthermore, legal issues can occur if the building fails or problems arise as responsibilities are not clearly defined. Also, the exchange of data between stakeholders is still a matter of improvement to guarantee a lossless and reliable transmission of information between different parties and programmes.

Currently, in view of railway infrastructure BIM is not advanced enough for productive use, as a sufficient information model and exchange format for the railway specific requirements is missing.

2.4 Sample Data Set

Thanks to the kind support of the Technical University of Munich (Chair of Computational

Modeling and Simulation) and buildingSMART International a sample data set of the IFC-Alignment scheme can be found in the annex. It is intended to give readers of this paper an idea of how an .ifc file looks like. The correctness and completeness is not guaranteed.

As data sets of the bSI SPEC Rail are not yet available in Roman alphabet the IFC-Alignment 1x1 was chosen as a representative IFC example data set. The example only refers to the vertical alignment. The whole alignment schema further contains information about the horizontal alignment and the terrain. Obviously, this information needs a lot more data and thus the extent would go beyond the scope of this paper.

The Chair of Computational Modeling and Simulation of the Technical University of Munich kindly provided a screenshot of the modelled data:
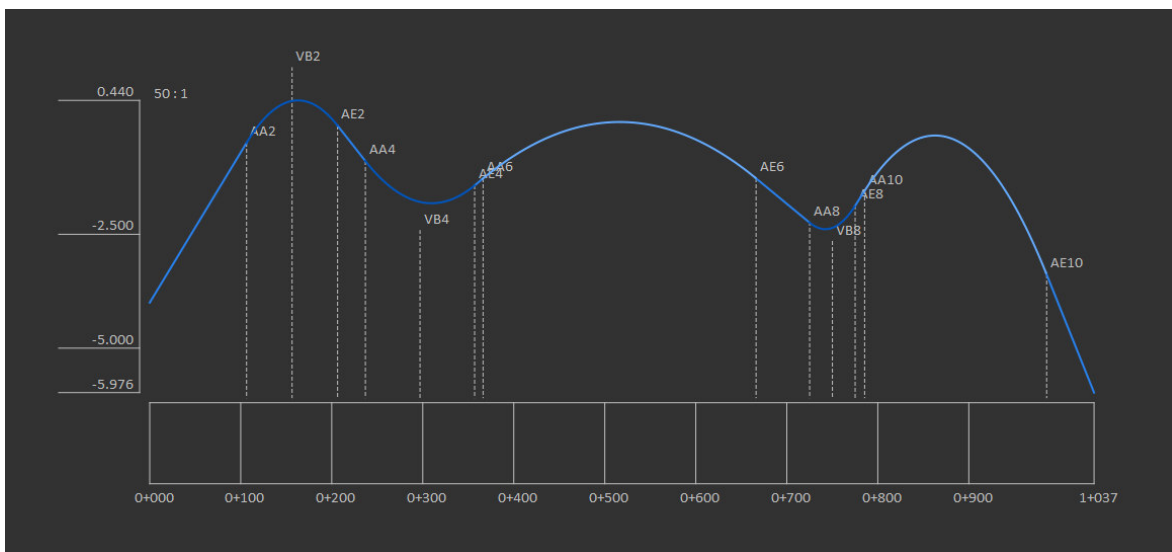
Illustration 2.10: Visualized IFC vertical alignment data.

```
ISO-10303-21;
HEADER;
FILE_DESCRIPTION(('IFC4X1'),'2;1');
FILE_NAME('OIP Revision 1721/E.1.1 Vertical Alignment/vertical-alignment-IfcAlignment1x1.ifc','2016-12-21T14:44:53',(''),(('',''),'','IfcAlignment','');
FILE_SCHEMA(('IFC4X1'));
ENDSEC;
DATA;
#1=IFCPERSON($,'User (FamilyName)','User (GivenName)',$,$,$,$,$);
#2=IFCORGANIZATION($,'TUM','Chair of Computational Modeling and Simulation',$,$);
#3=IFCAPPLICATION(#2,'RTM','TUM Open Infra Platform 2015','OIP');
#4=IFCPERSONANDORGANIZATION(#1,#2,$);
#5=IFCOWNERHISTORY(#4,#3,$,.NOCHANGE.,$,$,$,0);
#6=IFCDIMENSIONALEXPONENTS(0,0,0,0,0,0,0);
#7=IFCPROJECT('2yiRXK4fz779zOZ1YaBR3y',#5,'IfcAlignment Project',$,$,$,$,(#22),#8);
#8=IFCUNITASSIGNMENT((#9,#10,#11,#12));
#9=IFCSIUNIT(*,.LENGTHUNIT.,$,.METRE.);
#10=IFCSIUNIT(*,.PLANEANGLEUNIT.,$,.RADIAN.);
#11=IFCSIUNIT(*,.AREAUNIT.,$,.SQUARE_METRE.);
#12=IFCSIUNIT(*,.VOLUMEUNIT.,$,.CUBIC_METRE.);
#13=IFCCARTESIANPOINT((0.,0.,0.));
#14=IFCAXIS2PLACEMENT3D(#13,$,$);
#15=IFCLOCALPLACEMENT($,#14);
#16=IFCSITE('2spzfmWBDD58mtgG6NLQqU',$,'Terrain surface','My description.',$,#15,$,$,$,$,$,0.0000000000000000000,$,$);
#17=IFCPROJECTEDCRS('EPSG:31467','EPSG:31467 - DHDN / 3-Degree Gauss-Krueger Zone 3','EPSG:31467',$,'Gauss-Krueger','3',#18);
#18=IFCSIUNIT(*,.LENGTHUNIT.,$,.METRE.);
#19=IFCRELAGGREGATES('1Up__QCnX8JhFmwGMhYZQK',$,$,$,#7,(#16));
#20=IFCRELCONTAINEDINSPATIALSTRUCTURE('0wl2QBy_9BBv$PWVeztWJo',$,$,$,(#23),#16);
#21=IFCMAPCONVERSION(#22,#17,-353.28449668230399539,-434.28045784126197759,0.00000000000000000000,$,$,$);
```

Illustration 2.11: Extract of vertical Alignment IFC 1x1 data set.

3 RailTopoModel

3.1 Overview

3.1.1 General Information

RailTopoModel (RTM) is a logical infrastructure data model aiming at international standardization for the description of railway systems (network topology, infrastructure and the whole lifecycle of operations). It is the result of continuous collaborative work of the UIC RailTopoModel Expert Group, in which various Infrastructure Managers from all around Europe take part. Together with the development of the RTM data exchange format railML® 3, RTM is the central outcome of the UIC (International Union of Railways) ERIM (European Rail Infrastructure Masterplan) project. The ERIM Task Force has been working towards a common infrastructure master plan since 2004 and transferred into the UIC RailTopoModel Expert Group over time. [4, 29, 47]

3.1.2 Development Process and Status

After recognizing that a sufficient standard on railway modelling and a common exchange format for railway topology data was non-existent up until the year of 2012, a group of cooperating Infrastructure Managers (IM) proposed to UIC and railML.org to collaboratively develop a solution for the sector. As a result, the project RTM was started in 2013 with a feasibility study worked out by the Swiss company trafIT. The ERIM Task Force of the UIC requested an investigation whether "an international infrastructure data model for railway topology and corresponding common data exchange format could be achieved" [47]. The study was dedicated to analyse already existing models, such as RINF (ERA), Inspire (EU JRC), ARIANE (RFF, France), InfraNet (Infrabel, Belgium), Banedata (Jernbaneverket, Norway) and RINM (Network Rail, United Kingdom). They specifically looked at the railML compatibility of a future model, proposing a road map and estimating the costs of developing a common topological model and corresponding data exchange format. trafIT concluded that the development of such a model would be feasible, though suggested to establish a core (iron network) with an extension mechanism, rather than developing a unique model covering all aspects. This shall enable the incorporation of national or functional characteristics. Furthermore, they recommend to standardise the core model and the format to achieve interoperability instead of centralizing the database; to develop RailTopoModel in phases with direct case-involvement, and to offer a model for railways who do not dispose their own model or wish to improve their current model. The results were presented during the 1st UIC RailTopoModel and railML conference on the 17th September, 2013 in Paris. [31, 35, 47]

Due to the positive approval of the feasibility study, the UIC RTM Expert Group has been continued to work on defining the RailTopoModel. Semi-annually, RailTopoModel conferences

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were held at UIC´s headquarter in Paris to inform all interested parties about the status and discuss the further approach. In autumn 2014, RTM V1 was presented along with a road map of the railML3 schema for infrastructure. A major milestone was reached in spring 2016. During the 6th RailTopoModel conference, RTM was presented as the new IRS 30100 - an open and free industry standard. IRS is the abbreviation for International Railway Solution and refers to standards published by the UIC. In former times, they were known as UIC Leaflets. The IRS 30100 is publicly available for download on the RTM website. [31]

The RailTopoModel is a complementation of the ISO-standards (International Organisation for Standards) for geographic information (ISO 191xx) and is set up with semantics following the EN 28701:2012 "Identification of fixed objects in public transport". [4]

The UIC RailTopoModel Expert Group is persistent and will enhance the IRS 30100 in the next years. Currently, a yearly update is planned. The working group has already announced a roadmap for RTM extensions during the 7th UIC RTM and railML conference in November, 2016. Until the end of 2017, the two dimensions of Geometry and Life Cycle will complement the already existing Positioning and Location dimensions. Also, the packages Installations, Interlocking, Projects & Works, Physical Assets, Power, Traffic Management, and Train Model shall be added successively to the existing Track package. [30]
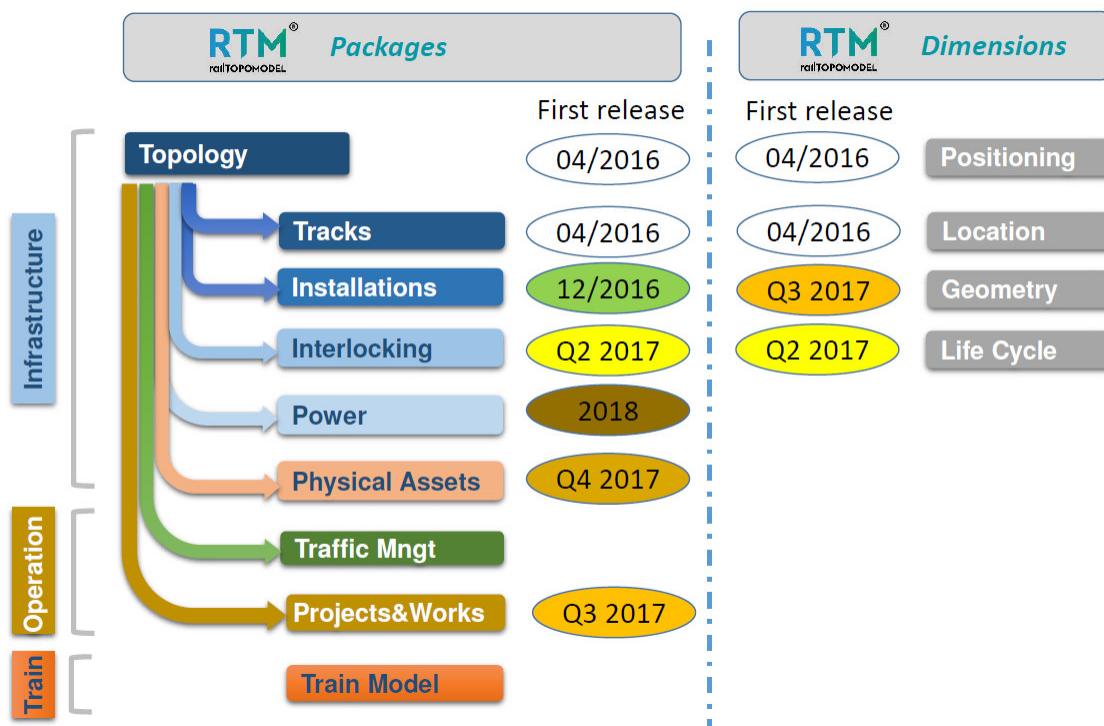

Illustration 3.12: Road map of RTM development. [30]

3.1.3 Scope of Application

RTM is designed to be applied in all business relations. Whether it focusses on intra-company relationships , cross departmental topics, inter-company relationships on a national level or international cooperation between countries or even between organisations and the EU, the

RTM Expert Group claims to simplify data exchange and thus to save costs and time in the fields of operation, legal affairs, and technology. For instance, RTM leads to synergistic effects when used internally in technical or operational fields, because it enables a standardised data exchange between the involved parties and substitutes different IT technologies and definitions. E.g., the planning and monitoring team of operations can easily exchange the relevant information needed for timetabling which leads to a simplification, acceleration, and less-error prone process. [45]

Furthermore, one major domain of application of RTM is the simulation. RTM is designed to model complex systems (systems of systems) and is therefore well adapted to fit different usages without neglecting the global consistency. An example in this area is combining multiple, consistent, simulation engines (routes and interlocking, track geometry and train gauge, power supply and train consumption, etc.) to best fit the needs. [45]

When collaborating with external businesses such as other IM´s or suppliers and sub-contractors, information can be exchanged easily due to the standardised interface of RTM which again leads to time and cost savings. Typical exemplary applications are the information exchange of IM´s with ETCS (European Train Control System) suppliers, maintenance sub-contractors or railway undertakings. Furthermore, RTM eliminates vendor lock-in. [45]

In the international context, RTM represents a model that can be used as a development foundation by railway supplier industries e.g. IT, interlocking, etc., and thus supports inexpensive, universal applicable solutions. Moreover, RTM can be used as a standardised data exchange model within rail corridors and international organisation e.g. RNE (RailNetEurope). A last aspect of the application scope of RTM is the legal aspect. RTM can be used to provide the required data for legal policies, such as the TEN-T (trans-European transport) network or RINF (Register of Infrastructure), efficiently and helps to reduce the bureaucratic burden. [45]

To ensure that all the above listed use cases can be fulfilled it is of great importance to specify a standardised data exchange format. RailTopoModel defines business objects and their attributes and is not suitable for data transmission. Therefore, an important currently ongoing use case of RailTopoModel, is the development of railML3. railML is an XML-based data exchange format, which is going to be explained further in this paper. railML3 is a new version, which is currently developed in full compliance with RailTopoModel. In parallel, also a generator for object-orientated language (Java, C#) is developed enabling the direct usage of RTM in IT developments. [45]

Currently, RTM is tested in various countries and application areas. For instance, it is used in France to maintain the Register of Infrastructure (RINF). In Germany, it supports on-board positioning systems and infrastructure recording, and in Norway RTM eases the process of capacity planning. railML is part of the development of ETCS in Belgium and France. [44]
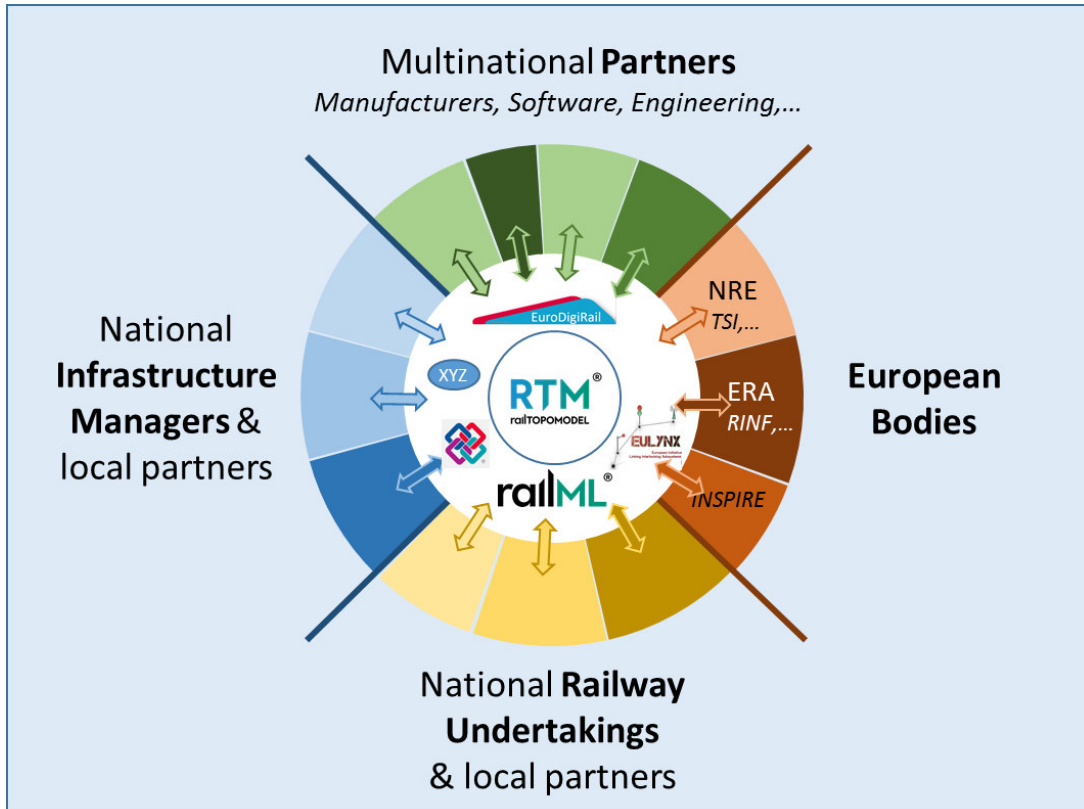
Illustration 3.13: Ideal cooperation situation of RTM and railML.[45]

3.2 Technical Details

3.2.1 Architecture

The IRS 30100 or RailTopoModel is based on the Unified Modelling Language (UML) V2.4.1 (4). UML is a general-purpose modelling language, which provides a standardised way to visualize the design of a system. RTM uses class diagrams to describe the structure by representing the different classes, their attributes, operations (or methods), and the relationships amongst the objects.

The network topology, the foundation of the RailTopoModel, is based on graph theory as topology is only logical and not dependent on any physical or technical items to represent it. One important feature of RTM is that network topology is not represented in the usual view which shows tracks as edges and switches as nodes. The graph theory requires all resources to be nodes as edges represent the relations between the resources. Therefore, both tracks and switches are represented by nodes in RTM and derive from a so-called "NetElement" class. This principle called connexity graph is consequently applied in the model. It is described in detail in the publication "A multi scalable model based on a connexity graph representation" by L. GÉLY, G. DESSAGNE, P. PESNEAU AND F. VANDERBECK and was firstly presented in August, 2012 during the 12th International Conference on Computer System Design and Operation in the Railways and other Transit Systems, COMPRAIL 2010 in Beijing, China.[4, 45]
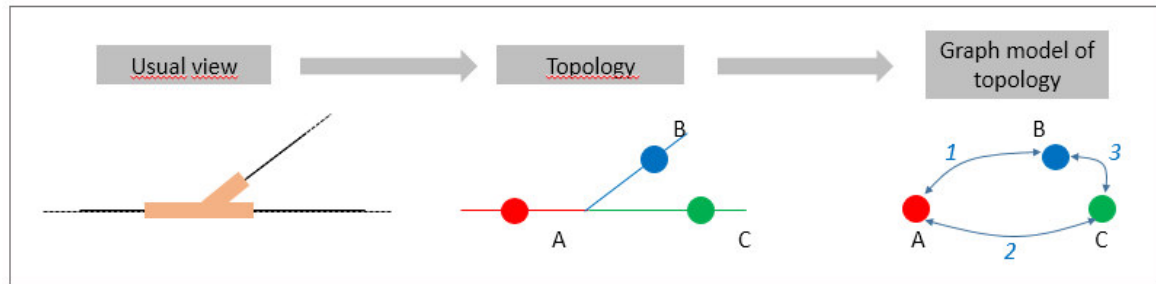
Illustration 3.14: Network representation in RTM. [4]

In order to meet all business needs and maturity levels the RTM consists of four detail levels, which are linked by aggregation rules: Nano, Micro, Meso and Macro. The Nano description level refers to actions of switches or crossings. It is the most enlarged level of detail and can be used for interlocking or asset management. The Micro level defines the network in the most similar way to the physical level. It has a large scale and is used for ETCS, interlocking, maintenance and asset (lifecycle) management. The Meso level provides functional information at track level between operational points. It is applied to visualise and process capacity properties of Sections of Lines. The capacity properties are linearly dependent on the number of tracks. The macro level has the smallest scale and represents the railway network at regional or national level. Use cases for the macro level would be the representation of a network of railway lines and station or timetabling information issues. These four described levels were predefined as they are most significant for railway operation. Nevertheless, the RTM allows to define an infinite number of other levels. In order to ensure a flexible change of level of detail the different levels are built by aggregating (or dividing) elements of the base level. This means that elements are grouped with declining scale, e.g. tracks and switches can be grouped to an Operational Point when zooming out. [4, 45]

Table 3.1: Overview of levels of detail and their elements in RTM. [4, 45]

Levels of Detail	Linear Elements	NonLinear Elements
Nano	Not defined	Not defined
Micro	Tracks connected to non-linear Elements	Switch points, network borders, buffer stops, possibly administrative points
Meso	Tracks connecting the Operating Points (SectionOfTracks)	Operating Points (e.g. stations, yards, junctions, boundaries)
Macro	Sections of line connecting non-linear Elements	Boundaries and major Operational Points

RailTopoModel currently (IRS 30100:2016) consists of four different packages, which can be distinguished by a specific colour: Base (grey), Topology (yellow), Positioning Systems (green), and Net Entities (light blue). The packages are further defined by UML classes and their objects. The Base package contains general data definitions and the definition of the network itself, e.g. the name of the network and the levels of details it is modelled for. The Topology package defines the topology of the network. The nodes are described by "NetElement", e.g. switches, tracks, operational points, independent of the level of detail. The edges are described by "Relation". The green package "Positioning Systems" is used for referencing the network and its components. Three different methods are available for positioning: intrinsic, linear and geographic. Linear positioning in railway business is based on a line of reference, for instance a track number with a start and end mileage. The geographic positioning builds up on geodetic and geometric coordinate systems. Intrinsic positioning is realised by assigning the value 0 to the start and the value 1 to the end of a linear element on the network. Nonlinear elements do not need to be numbered. The fourth package Net Entities allows to describe the network further beyond the topology. Net entities are physical elements, for example tunnels, bridges, signals, or immaterial objects, such as speed limits or radio coverage area. [4, 45]

The detailed description of all packages their classes and attributes as well as the associations amongst them can be found in detail in the IRS 30100 document. It is available for download on the RTM website: `www.railtopomodel.org`. [4, 45]
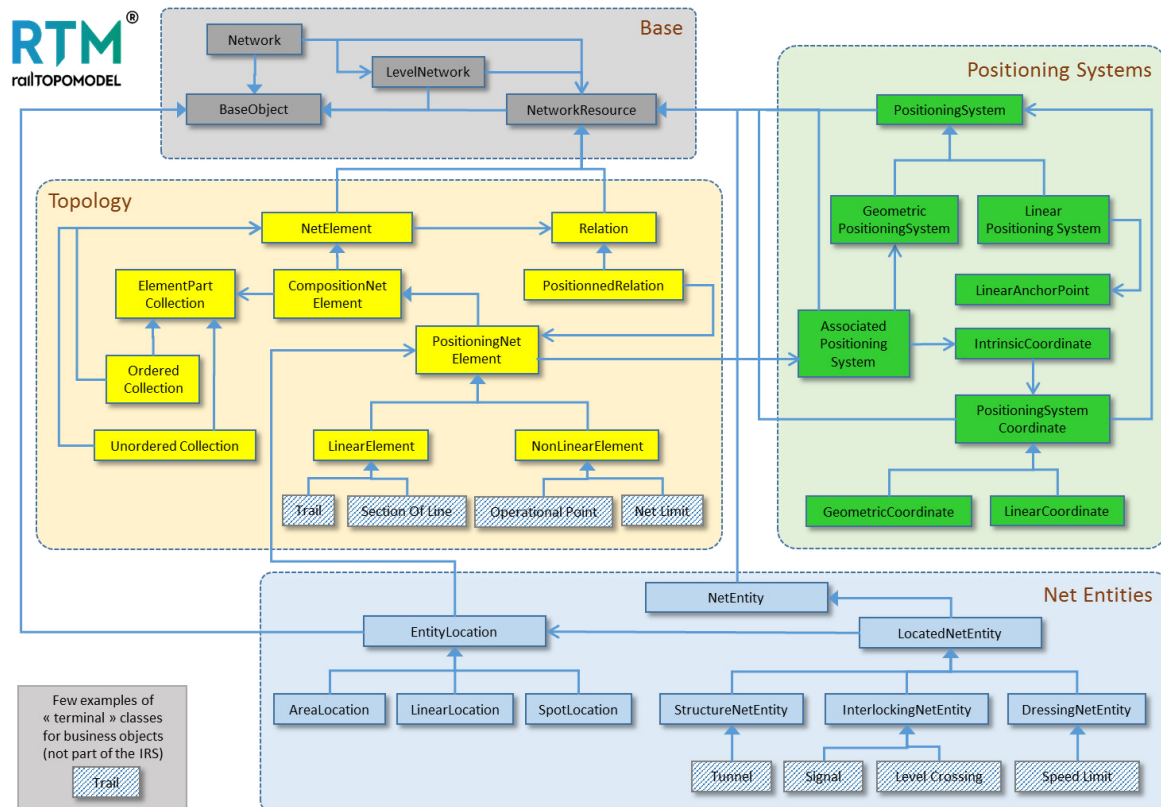
Illustration 3.15: RTM model architecture. [4]

3.2.2 Data Exchange Format – railML®

RailTopoModel solely is not designed for exchanging data, as it is a model and not a language. Therefore, railML.org is currently developing a new version of railML® (railML® 3), completely aligned to the RailTopoModel. railML® (railway Markup Language) is an XML-based data exchange format fitted to the needs of the railway industry.

Since 2002, the railML.org initiative is dedicated to developing and enhancing a standardised open-source data exchange format. Originally initiated from German and Swiss industry parties, it today consists of a diverse community from all over Europe. Infrastructure Managers, software companies, manufacturers, consulting firms, universities, governmental and local transport authorities and organisations as well as Railway Undertakings and research institutes are partners of railML.org and participate actively in the development process. The first productive version, railML® 1.0, was released in December 2005, in November 2009 railML® 2.0 was published, currently railML 2.3 is the official version though work for railML® 3 is ongoing. The planned release date for railML® 3.1 is September 2017, railML® 3.0 is only an alpha version not intended for any productive use. At present railML® consists of three different subschemas: Timetable, Rolling Stock and Infrastructure. A fourth subschema, Interlocking, is under construction and is announced to be published together with railML® 3. [40, 41]

The development of railML® takes place in working groups of the different subschemas. - The currently active working groups Infrastructure, Interlocking and Timetable meet once

every two to three months to discuss the further modelling strategy. The groups are led by an assigned subschema coordinator. Furthermore, all work is documented in a railML® Wiki, and the railML® Forum provides an open platform for discussion and improvement proposals that is managed by the railML® subschema coordinators. Of most interest for the RailTopoModel is the ongoing railML® 3 development in the railML® Infrastructure group, also called UIC RTM Expert Group. [43]

The Infrastructure subschema consists of information about topology, coordinates, geometry, railway infrastructure elements (e.g. balises, level crossings, platform edges) and immaterial, located elements, such as speed limits, track conditions, etc. It currently contains 206 different elements. railML® 3 is being developed on the fundament of the RailTopoModel and can therefore act as an exchange format for every infrastructure data base following the RTM concept. [43, 45]

In general, the development work at railML.org proceeds the following way:

1. Input from the community in form of use cases (wiki.railml.org)

2. Consolidation of use cases by the subschema coordinator and transformation into trac.railml.org

3. Modelling the requirements as a UML class model with help of Enterprise Architect

4. Specification of required elements (mandatory and optional) and attributes in an Excel file

5. Unification of all components and publication as an official document "railML® Use Case Definition"

6. Preparation of an example file

The legally relevant output of all railML.org work are railML® XSDs. An overview about all use cases can be found in the railML Wiki. Most relevant for the development of railML 3 Infrastructure, and therefore RailTopoModel is the Network Statement use case which defines the access and usage requirements of the rail network of the Infrastructure Manager. [43]

To conclude, RailTopoModel and railML® 3 aim at forming a standardised railway exchange format solution with multiple benefits for the sector.

3.3 Assessment

3.3.1 Advantages

Clearly, the RailTopoModel has a wide range of advantages if implemented in the intended way. As RTM is developed on the basis of use cases, prepared by the sector, one can be assured that all needs of the railway industry are respected and implemented as far as possible. Of course, the process of enhancement is labour intensive and therefore takes time, but work is ongoing and the RTM/railML community is eager to achieve challenging goals.

The sector consisting of all railway operating, infrastructure and supplier companies, will ideally benefit in various entities when investing and applying RTM and railML [44, 45]:

- Prevention of duplicate efforts in different departments or companies and fostering of collaboration and exchange of experience amongst them.

- Elimination of repetitive and labour intensive IT developments due to incompatible interfaces.

- Reduction of long development times in IT projects.

- Improvement/establishment of data exchangeability and compatibility amongst different transnational stakeholders.

- Increase of quality in data exchanges. Data losses and mismatches are avoided.

- Time, cost and resource savings enable capacity for innovation.

- Significant return of investment

3.3.2 Disadvantages

As both RTM and railML are industry driven initiatives, they are highly dependent on the contribution and participation from members. Not only financial input is required but also assistance in the field of documenting new requirements and use cases as well as testing or reviewing new developments is of great importance.

Problems can occur on one hand if there is missing engagement of the industry leading to substantial lack/delay of developments progress and on the other hand if the immaterial input is characterised by a certain country/region. This can either be caused by a supremacy of one or more countries/industries or by insufficient participation of other European countries/industries. In order to develop a standardised data exchange format that is equally applicable for all European railway stakeholders it is of big importance to identify and include the needs of all.

3.4 Example Data Set

Thanks to the kind support of railML.org a sample data set of the railML 3 scheme can be found in the annex. It is intended to give readers of this paper an idea of how a .railml file looks like. The correctness and completeness is not guaranteed.

The sample data were provided by railML.org under the following restrictions:

- The access to the railML v3 Alpha versions is restricted to active railML members.

- The work is based on "give and take". All beta tester/users of railML v3 are kindly ask to react on every new developer/alpha version released by railML.org. This feedback may range from error reports to simple confirmation like "works for me" (with

example). The further development will focus on the feedback from the users and therefore we kindly ask to send us back ideas and feedback.

The provided example railML 3 data set describes the following example network. The picture was kindly provided from railML.org together with the railML 3 example data set, which can be found in the annex.
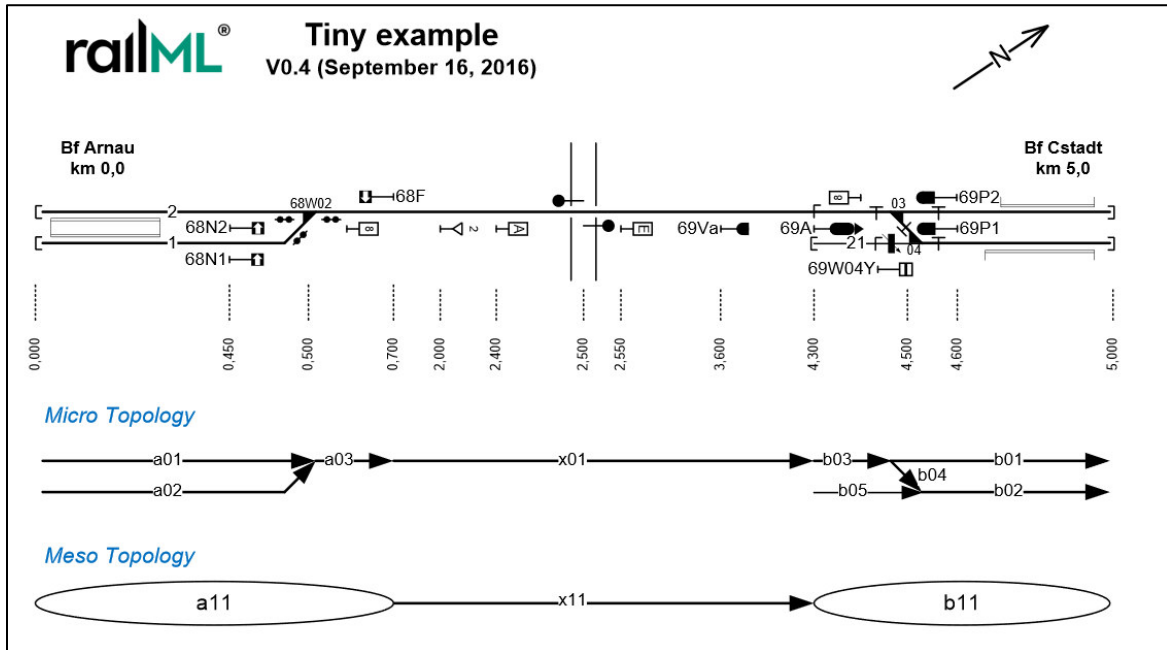
Illustration 3.16: railML 3 example network – German notation.

As railML.org operates in various different countries the railML 3 example is not only available in German notation. Currently also a Norwegian version is available and further countries (e.g. France) are in development.
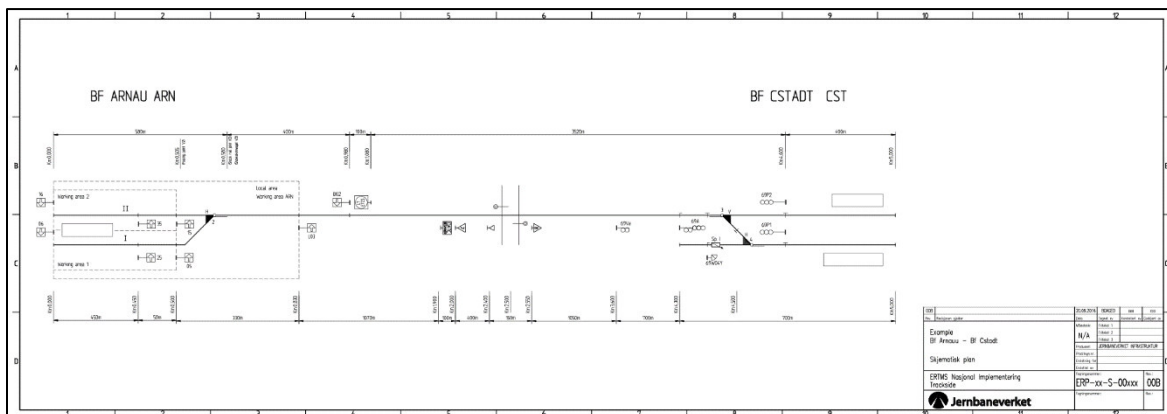
Illustration 3.17: railML 3 example network – Norwegian notation.

```
railML_TinyExample_v04_160930.xml

1    <?xml version="1.0" encoding="UTF-8"?>
2   <railML xmlns="http://www.railml.org/schemas/2015"
3           xmlns:gml="http://www.opengis.net/gml"
4           xmlns:dc="http://purl.org/dc/elements/1.1"
5           xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
6           xsi:schemaLocation="http://www.railml.org/schemas/2015 ../schema/railml3.xsd"
7           version="3.0.1">
8
9     <infrastructure>
10      <topology>
11        <netElement id="ne_a01" type="track">
12          <relation ref="nr_a01a02"/>
13          <relation ref="nr_a01a03"/>
14        </netElement>
```

Illustration 3.18: Extract railML 3 example data set.

4 Comparison of the Two Models

4.1 Criteria of Comparison

In order to compare the two models the following criteria are considered:

- Modelling language: What language is used to model the matter?

- Model architecture: How is the information model structured?

- Exchange format: What exchange format is used?

- Domain of discourse: What specific fields of interest are modelled?

- Field of application: Where is/can the model (be) applied today/in future?

- Level of implementation: What is the status of development and implementation areas?

- Tool compatibility: How compatible is the exchange format?

- Issuing organisation: Which organisation has the lead in development?

- Licence: Which licences do the models subject to?

In the following the RailTopoModel and its related data exchange format railML3 will be compared with the bSI SPEC Rail (IFC Rail). The restriction on the side of BIM is made to allow a comparison of corresponding formats in the railway domain.

4.1.1 Modelling Language

The RailTopoModel is based on UML (Unified Modelling Language), whereas the bSI SPEC Rail is defined in EXPRESS and EXPRESS-G. Both formats are open formats and platform independent, so that a conversion into objected oriented languages is easily possible. [38]

RTM´s data exchange format railML3 uses the RTM UML to generate XSD´s. The bSI SPEC does not contain any XSD specifications, though it can be assumed that this will be an integral part in future as the official IFC version 4 contains XSD specifications in addition to the EXPRESS specification. [2, 4]
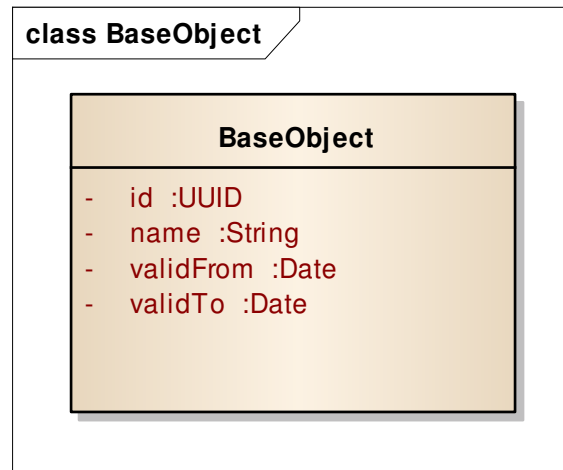
Illustration 4.19: Example of RTM UML class specification. [4]
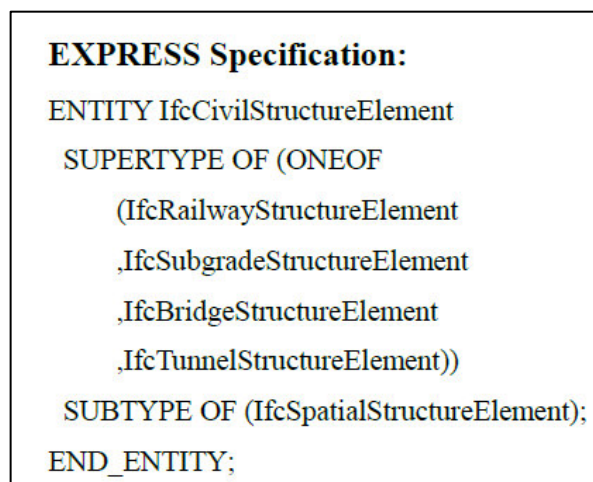
Illustration 4.20: Example of bSI SPEC Rail EXPRESS specification. [2]

4.1.2 Model Architecture

Big differences exist in the model architecture. RTM builds up on packages, each focusing on a specific aspect of the model (topology, net entities, base, and net element). The bSI SPEC Rail extends the typical IFC layer architecture by the needs of railway infrastructure. An Alignment, Geology, Subgrade, Bridge, Tunnel, Drainage, Track and Station Domain were introduced. Each domain contains schema, type, entity, and property set definitions, which are specific for the equivalent domain. The bSI SPEC Rail builds up on the IfcCivilStructureElement, which is inherited from the IFC4 IfcSpatialStructureElement. [2]
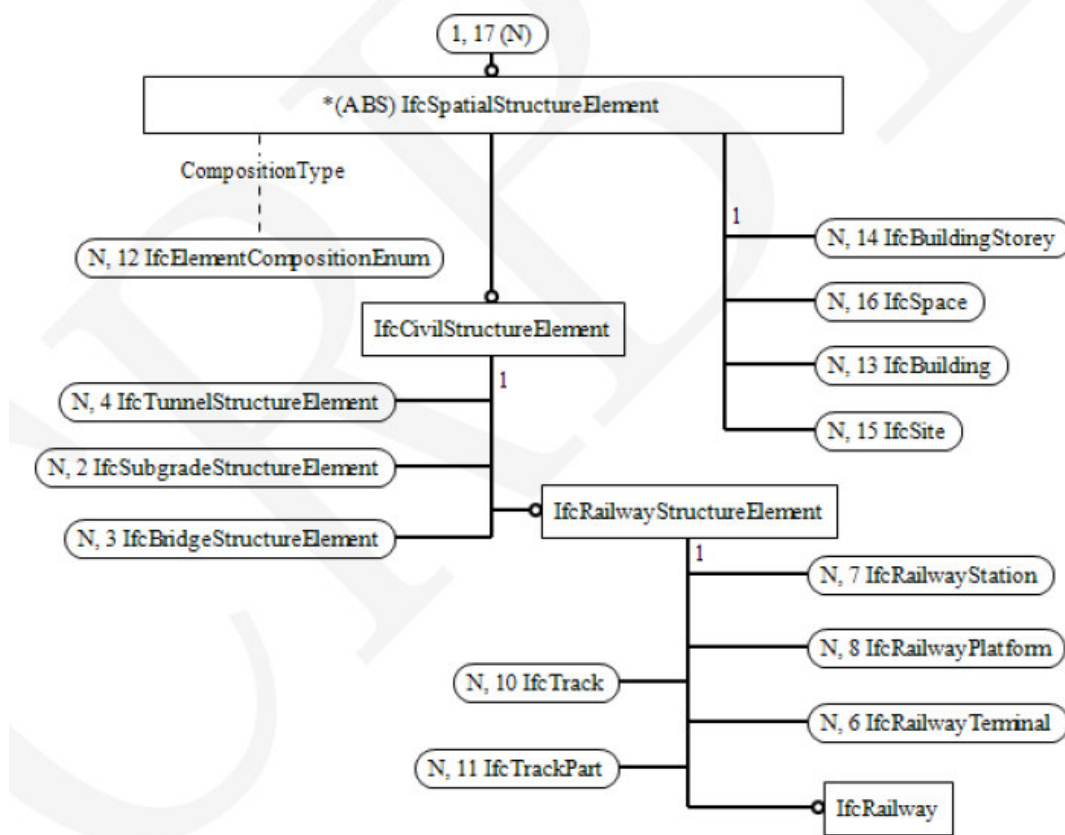
Illustration 4.21: EXPRESS-G diagramm for IfcSpatialStructureElement. [2]

RTM firstly focuses on displaying the topology of a railway network as a whole in different layers of detail. Subsequently the specifications of the different network elements can be defined with the packages. The main class of the RTM is "Network". "Network" consist of the description levels defined in "Level Network" and further specifications defined in the class "NetworkResource". [4]
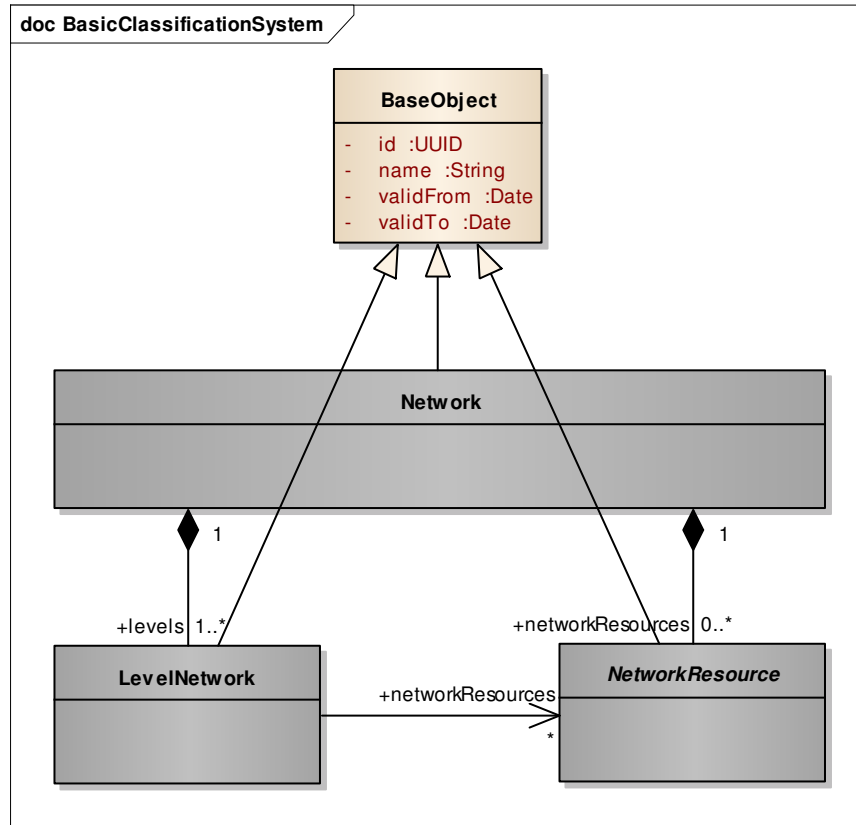
Illustration 4.22: UML diagramme of RTM. [4]

4.1.3 Exchange Format

The bSI SPEC Rail is designed upon the guidelines of IFC4, which implies that the equivalent exchange format is .ifc. .ifc is based on the EXPRESS language and is fragmentally human-readable. buildingSMART International has started an approach to specify its standards not only in EXPRESS language but also in XSD schemes, which allow a representation in XML-format. XML is a human-readable worldwide established mark-up language. The corresponding exchange format is named .ifcxml and is implemented in the IFC4 release. One can assume that the official IFC Rail release will dispose of both EXPRESS and XSD specification and therefore both formats .ifc and .ifcxml will be permitted. [14]

Unlike IFC, RTM only consists of an information model. The data exchange format is directly derived from RTM as .railml. railML is an XML-based exchange format with XSD-specifications, dedicated to the rail domain and its multiple businesses (e.g. infrastructure design and maintenance, routes and interlocking, scheduling, rolling stocks, etc.).

4.1.4 Domain of Discourse

The bSI SPEC Rail describes a model aiming at construction information. It can be easily seen from the additionally created domains that the focus is to represent the buildings and constructions of railway lines in detail. RTM on the other hand describes the railway network from the perspective of operation.

For example, the bSI SPEC describes a bridge or tunnel in such detail as construction workers would need the information in order to build/maintain the bridge or tunnel. The bridge, for instance is characterised by its arch segment type, cable type, bed stone type, falling prevention device type, etc. All this information is irrelevant for the RTM, a bridge is only recorded as a NetElement with a position in the network and its characteristic related to operation (gauge) and life cycle (change in structure). [2, 4]

However, RTM describes the position of net elements (e.g. tunnels, bridges, signals, balises) in a very precise way. Currently two main methods are used for this: linear and geographic positioning. The bSI SPEC only touches the positioning in their alignment schema superficially with the IfcChainageSystem element. [2, 4]

Nevertheless, the positioning of net elements or topology are potentially similar in both models and could represent an overlap, a starting point to link both models. It would be of interest to further analyse the specific method of positioning in RTM and the IFC Alignment.

4.1.5   Field of Application

As the bSI SPEC Rail is currently revised by an international committee to meet the requirements of a generalised transnational approach a specific field of application is not existent. Nevertheless, it can be assumed that a future official release version will be implemented in a similar way in the railway domain as IFC4 is implemented in building construction. Thus, the main application area of IFC Rail would be the exchange of construction relevant information between different stakeholders of railway infrastructure projects. It can therefore contribute to BIM in the phase of construction and operation/maintenance, though limitations are present when it comes to operationally relevant "immaterial" infrastructure, such as train protection elements, interlIFocking, etc.

RTM was developed to fulfil the need of a topological infrastructure model for railways. In former times, every railway or EU initiative had to develop its own data model to create an asset data base. Hence multiple different interfaces emerged, which led to poor quality data exchanges and high management costs. Today RTM serves as a generic open model applicable for all railways. The French Infrastructure Manager SNCF Réseau, for instance, has developed its global model for railway business objects "Ariane" in accordance with the RTM. The Ariane Model contains the descriptions of all functional objects and properties of the French network and is continually enhanced. In addition to topology, referencing and topography also the train circulation and engineering-maintenance projects were added to Ariane aiming at providing a model to support Infrastructure Management and Operations in future. [44]

4.1.6   Level of Implementation

As already written in the previous chapter, the bSI SPEC Rail is not yet an official buildingSMART standard. Therefore, it is unlikely that it is already implemented somewhere. As the China Railway BIM Alliance is the issuer and the official implementation date of the document is the 1st January, 2016, it might already be implemented in China. However, it is

hard to retrieve information in this field due to the language and distance barrier.

RTM on the other hand is already part of various applications. For example, the data exchange format railML3 and the French asset database Ariane are developed on the basis of RTM. Furthermore, several railways are considering on using RTM for future Infrastructure Data Management. For instance, Jernbaneverket is thinking of simplifying the ERTMS management in Norway with the help of RTM. Further HS2 Ltd. is interested in integrating RTM in their asset information management system of the new high speed rail project in the UK. [22, 48]

4.1.7 Tool Compatibility

The bSI SPEC Rail itself is not yet compatible to any tools as it has not been adjusted to an official IFC format. Nonetheless it will probably become one sometime in future and thus tool compatibility will be similar to the now existing IFC4 format. IFC is the buildingSMART data model and official exchange format of openBIM, the vendor independent program for an open and documented collaborative framework in the building industry. It is internationally approved and especially throughout Europe very popular. Hence a big variety of tools from different vendors are available that can import and export .ifc files. The www.buildingsmart-tech.org website lists IFC-compatible applications sorted by type. Currently 204 applications are contained in the database. [15]

When it comes to RTM, railML3 is the exchange format one must look at when interested in tool compatibility. As railML3 is not officially released yet, it does not have any fully compatible tools. Nevertheless, railML.org is developing this standard since 2002 and the previous railML versions (railML 1.0 – railML 2.3) dispose of various compatible software solutions. For example, a railML viewer and validator – railVIVID – was specially developed by the railML.org consortium and will be extended to the new railML3 version. railML.org provides an overview of railML compatible software on their website `www.railml.org`. [42]

4.1.8 Issuing Organisation

The bSI SPEC Rail was issued by the China Railway BIM alliance on the 29th December, 2015. It later became a publicly available SPECification of buildingSMART International and is currently being analysed by an international expert committee assigned by buildingSMART International. Aim is to develop an IFC Rail schema which can be integrated together with other infrastructure schemas in the IFC 5 release. buildingSMART itself is a worldwide non-governmental and non-profit authority aiming at providing openBIM standards to support the usage of open sharable asset information. They believe that this will have a significant effect in cost, value, and environmental improvement. Currently buildingSMART is represented in 18 chapters across the world: Australasia, Benelux, Canada, China, France, German speaking, Hong Kong, Italy, Japan, Korea, Malaysia, Nordic, Norway, Singapore, Spain, Switzerland, United Kingdom & Ireland and the USA. The work is financed by several sponsors which are listed on their website, e.g. Autodesk, Trafikverket, German Federal Ministry of Transport and Digital

Infrastructure, etc. Furthermore, membership fees are charged and members are asked to contribute with active participation to the developments. [14]

The RTM arised out of the UIC ERIM project and was developed by the ERIM Task Force in strong collaboration with railML.org. UIC funds the developments through the membership fees of its railway members. Moreover, the community of railML.org, which consist of railways, consultancies, universities, software companies and research institutes from all over Europe support the developments by participating actively in the development process. railML.org focuses on simplifying the data exchange between railways and contractors by providing a universal, XML-based, open-source data exchange solution. It is an open, non-profit organisation according to German law. Currently no membership fees are charged.

4.1.9 Licence

In order to legally use RTM and its railML schema, users must respect the Creative Commons Attribution-NonCommercial-NoDerivs 3.0 Unported License. The licence implies that one is free to copy and redistribute the material as long as the usage is attributed correctly and potential changes are indicated, the usage does not involve commercial purposes and the schema is not derived. Furthermore, the schema is not allowed to be offered for download anywhere else except from the railML.org website and prior to usage a registration at railML.org is necessary. All railML interfaces have to be certified prior to productive use and railM.org is to be informed about any handbooks, leaflets, etc. where railML is mentioned. [42]

In spite of detailed research, no information about the licence terms of IFC could be found. A written request sent via email on the 15th of January, 2017 remained unanswered until the submission deadline of the paper. Therefore, no further assessments can be made.

4.2 Findings

In general, the two analysed information models seem to be quite different as all the above discussed criteria show deviations from one another. It remains to be seen what aspects of the bSI SPEC Rail are adjusted in the process of adapting it to European/international requirements.

Both models have in common that they are tailored to railways, though the distinct scope of application is different. RTM focuses more on the global and detailed functional description and technical characteristics of the network for operation (train operation and asset management), whereas the bSI SPEC Rail is rather specialised in the construction of railway infrastructure. Putting this into context with BIM leads to the thesis that the bSI SPEC Rail and RTM/railML are suited to support the different phases in the design, construction, operation and maintenance of the network. Whereas RTM is tailored to assist in early functional studies and simulation (e.g. intermodal flows, environmental studies). The bSI SPEC Rail rather supports the fine geometry design and construction process. Both can be used for maintenance and asset management. Nevertheless, one should keep in mind that the two exchange formats

of the models .ifc and .railml and the general architecture of the models are currently not compatible with each other. At the moment, only the bSI SPEC Rail would be applicable in the broader context of openBIM, as openBIM is based on the exchange of information in .ifc-format. However, at this point it is necessary to keep in mind that openBIM is only a part of BIM. RTM aims at providing an end to end model for the network life cycle management and operation.

4.3 Complementation

Due to the fact that RTM and the bSI SPEC Rail do not have many features in common they would complement one another profitable. Combining the construction-focused bSI SPEC Rail with the operationally-focused RTM would lead to a more holistic information model solution for railways. Finally, one can say that both models show a good approach to the complex system of railways, but neither embodies a perfect solution. Why should either party start developing the components of the other party newly if the adoption is a much quicker, easier and more promising option?

An important issue that needs to be clarified in near future by modelling experts is how the two architecture models can incorporate with one another. In my eyes the RTM approach of modelling the topology of a network with a connexity graph, breaking it down into layers and adding attributes to the network elements is strategic and logical. Especially as the railway domain requires very precise positioning in the time of ERTMS/ETCS, where the train driver is informed about all relevant track information via balises. With this strategy, one option would be to define the schemas of the bSI SPEC Rail (e.g. the bridge, tunnel and subgrade domain) as sub-packages of related functional objects of RTM. The Track Domain schema of bSI SPEC could be related to the Net Element (topology) package of RTM. The Bridge, Station or Tunnel Domain schema could be related to the corresponding Net Entities package.

Another option would be to embed the RTM into the bSI SPEC Rail schema. For instance, the referencing package of RTM could replace or enhance the chainage system of the bSI SPEC Rail.

An interesting fact, which is worth further investigation is that both models build up their elements on GUIDs (Globally Unique Identifier). It would therefore be possible to link the elements of the two models with this identifier. Additionally to the linkage via GUIDs a spatial and functional link of the elements is necessary to ensure conformity of the models.

Whatever scenario will be chosen, both projects should ensure consistency in common functional railway semantic, to support continuity in management and the usage of functional descriptions of multiple solutions based either on one or the other standard.

4.4 Enhancements for the Future

Looking at the six main dimensions of the Building Information Model - 3D-building data, costs, time and lifecycle facility-management - one can say that both models, RTM and the IFC Rail candidate do not fulfil all the dimensions. Probably this is a result out of the complexity of

railway networks and the need of having to model the asset before being able to add other dimensions.

Nevertheless, it would be of great value for the construction industry if costs were calculable. Also, the maintenance of the railway infrastructure would become much more predictable if costs/prices were assigned to the different elements.

The time dimension is of great importance and would benefit the whole society. First of all, an accurate time schedule for the construction phase helps to organise the process, allows every individual stakeholder to be informed, and leads to public acceptance of big infrastructure projects. After the construction is completed and the operation started, maintenance comes into play. Once more, an accurate time schedule of the repair works helps the construction firms in their planning but also supports the train operating companies with timetabling. A reliable train timetable and punctuality results in high customer satisfaction and is therefore an integral part of the company's performance.

A further idea of enhancement would be to integrate predictable maintenance of critical and important network elements (e.g. interlocking components) in the model. A signal lamp would therefore become an attribute which indicates at which date the illuminant was checked and/or exchanged. With the help of manufacturer specifications or even self-testing components described in a further attribute, the asset information model can predict the time at which the signal would most probably break down. Consequently, the illuminant will be switched only shortly before breaking down and resources can be saved.

5 Conclusion

Coming back to the introductory questions, one now can say that RTM and IFC Rail (bSI SPEC Rail) show significant differences. Especially the architecture of the models and the application field differ from another but also create great potential for complementation. Uniting both models would help build up a holistic model covering both important parts: Construction and operation of railways and their infrastructure.

A second major finding is that IFC incorporates information model and exchange format in one. BIM is only an umbrella term, defining the business processes on the way to the design, construction, operation and maintenance of assets in digital environment. The RTM/railML approach is slightly different. Here RTM is in charge of defining the model in UML and railML.org is developing the complementary exchange format - railML3 - on the foundations of these UML descriptions.

In order to progress with both models, an expert analysis focusing on the complementation of the models would be necessary. It is important to find out how the information model architectures can be combined with each other and how big the effort would be. In my eyes, of special interest is the comparison of the topology representation. How similar is the linear referencing approach of the RTM to the IFC Alignment and is this possibly an approach to link the two models?

Linking both models generates great potential to create one holistic information model for all needs of the railway industry. Yet this process is labour and time-intensive and needs to be fulfilled very thoroughly in order to achieve satisfying results.

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Annex

A Example Data Sets

A.1 IFC vertical Alignment 1x1 - Example Data Set

```
ISO-10303-21;
HEADER;
FILE_DESCRIPTION(('IFC4X1'),'2;1');
FILE_NAME('OIP Revision 1721/E.1.1 Vertical Alignment/vertical-alignment-
IfcAlignment1x1.ifc','2016-12-21T14:44:53',(''),('',''),'','IfcAlignment','');
FILE_SCHEMA(('IFC4X1'));
ENDSEC;
DATA;
#1=IFCPERSON($,'User (FamilyName)','User (GivenName)',$,$,$,$,$);
#2=IFCORGANIZATION($,'TUM','Chair of Computational Modeling and Simulation',$,$);
#3=IFCAPPLICATION(#2,'RTM','TUM Open Infra Platform 2015','OIP');
#4=IFCPERSONANDORGANIZATION(#1,#2,$);
#5=IFCOWNERHISTORY(#4,#3,$,.NOCHANGE.,$,$,$,0);
#6=IFCDIMENSIONALEXPONENTS(0,0,0,0,0,0,0);
#7=IFCPROJECT('2yiRXK4fz779zOZlYaBR3y',#5,'IfcAlignment Project',$,$,$,$,(#22),#8);
#8=IFCUNITASSIGNMENT((#9,#10,#11,#12));
#9=IFCSIUNIT(*,.LENGTHUNIT.,$,.METRE.);
#10=IFCSIUNIT(*,.PLANEANGLEUNIT.,$,.RADIAN.);
#11=IFCSIUNIT(*,.AREAUNIT.,$,.SQUARE_METRE.);
#12=IFCSIUNIT(*,.VOLUMEUNIT.,$,.CUBIC_METRE.);
#13=IFCCARTESIANPOINT((0.,0.,0.));
#14=IFCAXIS2PLACEMENT3D(#13,$,$);
#15=IFCLOCALPLACEMENT($,#14);
#16=IFCSITE('2spzfmWBDD58mtgG6NLQqU',$,'Terrain surface','My
description.',$,#15,$,$,$,$,$,0.00000000000000000000,$,$);
#17=IFCPROJECTEDCRS('EPSG:31467','EPSG:31467 - DHDN / 3-Degree Gauss-Krueger Zone
3','EPSG:31467',$,'Gauss-Krueger','3',#18);
#18=IFCSIUNIT(*,.LENGTHUNIT.,$,.METRE.);
#19=IFCRELAGGREGATES('1Up__QCnX8JhFmwGMhYZQK',$,$,$,#7,(#16));
#20=IFCRELCONTAINEDINSPATIALSTRUCTURE('0wl2QBy_9BBv$PWVeztWJo',$,$,$,(#23),#
16);
#21=IFCMAPCONVERSION(#22,#17,-353.28449668230399539,-
434.28045784126197759,0.00000000000000000000,$,$,$);
```

#22=IFCGEOMETRICREPRESENTATIONCONTEXT($,'Model',3,$,#14,$);

#23=IFCALIGNMENT('3uKfva$8L8RxroRRn$SYiB',$,$,'Achse - (2)',$,$,$,#24,$);

#24=IFCALIGNMENTCURVE(#25,#29,$);

#25=IFCALIGNMENT2DHORIZONTAL(0.00000000000000000000,(#26));

#26=IFCALIGNMENT2DHORIZONTALSEGMENT(.F.,$,$,#27);

#27=IFCLINESEGMENT2D(#28,0.56083327531814575195,1038.0898910365849588);

#28=IFCCARTESIANPOINT((0.,0.));

#29=IFCALIGNMENT2DVERTICAL((#30,#31,#32,#33,#34,#35,#36,#37,#38,#39,#40));

#30=IFCALIGNMENT2DVERSEGLINE($,$,$,0.00000000000000000000,106.43868347868300361,-4.00000000000000000000,0.03297020095473908520);

#31=IFCALIGNMENT2DVERSEGPARABOLICARC($,$,$,106.43868347868300361,100.00000000000000000,-0.49069521634995449944,0.03297020095473908520,1711.8272359552092894,.F.);

#32=IFCALIGNMENT2DVERSEGLINE($,$,$,206.43868347868300361,30.548038363430009667,-0.11453062251781709335,-0.025446909078096335149);

#33=IFCALIGNMENT2DVERSEGPARABOLICARC($,$,$,236.98672184211301328,120.00000000000000000,-0.89188377726621936858,-0.025446909078096345558,2859.2684664243251973,.T.);

#34=IFCALIGNMENT2DVERSEGLINE($,$,$,356.98672184211301328,9.2763020583819297826,-1.4273862602880100781,0.016521867694367017854);

#35=IFCALIGNMENT2DVERSEGCIRCULARARC($,$,$,366.26302390049494306,300.00000000001369926,-1.2741244249864394078,0.016521867694399838822,9081.8830036985036713,.F.);

#36=IFCALIGNMENT2DVERSEGLINE($,$,$,666.26302390050864233,58.840951904593339350,-1.2731599370035837637,-0.016515436019986628330);

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#38=IFCALIGNMENT2DVERSEGLINE($,$,$,775.10397580510198168,10.398654916624309408,-1.8728001159093139449,0.031401187925176113347);

#39=IFCALIGNMENT2DVERSEGCIRCULARARC($,$,$,785.50263072172629109,200.00000000002830802,-1.5462699987033374782,0.031401187925187465377,2465.7506515629438582,.F.);

#40=IFCALIGNMENT2DVERSEGLINE($,$,$,985.50263072175459911,52.587260314830359675,-3.3818341400497047289,-0.049787074745400554387);

ENDSEC;

END-ISO-10303-21;

A - 2

A.2 railML 3 – Example Data Set

```xml
<?xml version="1.0" encoding="UTF-8"?>
<railML xmlns="http://www.railml.org/schemas/2015"
    xmlns:gml="http://www.opengis.net/gml"
    xmlns:dc="http://purl.org/dc/elements/1.1"
    xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
    xsi:schemaLocation="http://www.railml.org/schemas/2015 ../schema/railml3.xsd"
    version="3.0.1">

 <infrastructure>
  <topology>
   <netElement id="ne_a01" type="track">
    <relation ref="nr_a01a02"/>
    <relation ref="nr_a01a03"/>
   </netElement>
   <netElement id="ne_a02" type="track">
    <relation ref="nr_a01a02"/>
    <relation ref="nr_a02a03"/>
   </netElement>
   <netElement id="ne_a03" type="track">
    <relation ref="nr_a01a03"/>
    <relation ref="nr_a02a03"/>
   </netElement>
   <netElement id="ne_b01" type="track">
    <relation ref="nr_b01b03"/>
    <relation ref="nr_b01b04"/>
   </netElement>
   <netElement id="ne_b02" type="track">
    <relation ref="nr_b02b04"/>
    <relation ref="nr_b02b05"/>
   </netElement>
   <netElement id="ne_b03" type="track">
    <relation ref="nr_b01b03"/>
    <relation ref="nr_b03b04"/>
    <relation ref="nr_x01b03"/>
   </netElement>
   <netElement id="ne_b04" type="track">
    <relation ref="nr_b01b04"/>
    <relation ref="nr_b02b04"/>
    <relation ref="nr_b03b04"/>
```

```xml
  <relation ref="nr_b04b05"/>
 </netElement>
 <netElement id="ne_b05" type="track">
  <relation ref="nr_b02b05"/>
  <relation ref="nr_b04b05"/>
 </netElement>
 <netElement id="ne_x01" type="track">
  <relation ref="nr_a03x01"/>
  <relation ref="nr_x01b03"/>
 </netElement>
 <netElement id="ne_a11" type="operationalPoint">
  <relation ref="nr_a11x11"/>
  <elementCollectionUnordered id="ecu_ne_a11">
   <elementPart ref="ne_a01"/>
   <elementPart ref="ne_a02"/>
   <elementPart ref="ne_a03"/>
  </elementCollectionUnordered>
  <associatedPositioningSystem id="ne_a11_aps_01">
   <intrinsicCoordinate intrinsicCoord="0">
    <coordinate ref="lco_001"/>
    <coordinate ref="lco_004"/>
   </intrinsicCoordinate>
  </associatedPositioningSystem>
 </netElement>
 <netElement id="ne_b11" type="operationalPoint">
  <relation ref="nr_x11b11"/>
  <elementCollectionUnordered id="ecu_ne_b11">
   <elementPart ref="ne_b01"/>
   <elementPart ref="ne_b02"/>
   <elementPart ref="ne_b03"/>
   <elementPart ref="ne_b04"/>
   <elementPart ref="ne_b05"/>
  </elementCollectionUnordered>
  <associatedPositioningSystem id="ne_b11_aps_01">
   <intrinsicCoordinate intrinsicCoord="0">
    <coordinate ref="lco_010"/>
    <coordinate ref="lco_013"/>
   </intrinsicCoordinate>
  </associatedPositioningSystem>
 </netElement>
 <netElement id="ne_x11" type="line">
```

```
  <relation ref="nr_a11x11"/>
  <relation ref="nr_x11b11"/>
  <elementCollectionUnordered id="ecu_ne_x11">
   <elementPart ref="ne_x01"/>
  </elementCollectionUnordered>
  <associatedPositioningSystem id="ne_x11_aps_01">
   <intrinsicCoordinate intrinsicCoord="0">
    <coordinate ref="lco_004"/>
   </intrinsicCoordinate>
   <intrinsicCoordinate intrinsicCoord="1">
    <coordinate ref="lco_010"/>
   </intrinsicCoordinate>
  </associatedPositioningSystem>
  <parameter ref="p_el_01"/>
</netElement>

<netRelation id="nr_a01a02" positionOnA="1" positionOnB="1" navigability="None">
 <elementA ref="ne_a01"/>
 <elementB ref="ne_a02"/>
</netRelation>
<netRelation id="nr_a01a03" positionOnA="1" positionOnB="0" navigability="Both">
 <elementA ref="ne_a01"/>
 <elementB ref="ne_a03"/>
</netRelation>
<netRelation id="nr_a02a03" positionOnA="1" positionOnB="0" navigability="Both">
 <elementA ref="ne_a02"/>
 <elementB ref="ne_a03"/>
</netRelation>
<netRelation id="nr_b01b03" positionOnA="0" positionOnB="1" navigability="Both">
 <elementA ref="ne_b01"/>
 <elementB ref="ne_b03"/>
</netRelation>
<netRelation id="nr_b01b04" positionOnA="0" positionOnB="0" navigability="None">
 <elementA ref="ne_b01"/>
 <elementB ref="ne_b04"/>
</netRelation>
<netRelation id="nr_b02b04" positionOnA="0" positionOnB="1" navigability="Both">
 <elementA ref="ne_b02"/>
 <elementB ref="ne_b04"/>
</netRelation>
<netRelation id="nr_b02b05" positionOnA="0" positionOnB="1" navigability="Both">
```

```
    <elementA ref="ne_b02"/>
    <elementB ref="ne_b05"/>
  </netRelation>
  <netRelation id="nr_b03b04" positionOnA="1" positionOnB="0" navigability="Both">
    <elementA ref="ne_b03"/>
    <elementB ref="ne_b04"/>
  </netRelation>
  <netRelation id="nr_b04b05" positionOnA="1" positionOnB="1" navigability="None">
    <elementA ref="ne_b04"/>
    <elementB ref="ne_b05"/>
  </netRelation>
  <netRelation id="nr_a03x01" positionOnA="1" positionOnB="0" navigability="Both">
    <elementA ref="ne_a03"/>
    <elementB ref="ne_x01"/>
  </netRelation>
  <netRelation id="nr_x01b03" positionOnA="1" positionOnB="0" navigability="Both">
    <elementA ref="ne_x01"/>
    <elementB ref="ne_b03"/>
  </netRelation>
  <netRelation id="nr_a11x11" positionOnA="0" positionOnB="0" navigability="Both">
    <elementA ref="ne_a11"/>
    <elementB ref="ne_x11"/>
  </netRelation>
  <netRelation id="nr_x11b11" positionOnA="1" positionOnB="0" navigability="Both">
    <elementA ref="ne_x11"/>
    <elementB ref="ne_b11"/>
  </netRelation>

  <level id="lv0" levelOfDetail="micro">
    <networkResource ref="ne_a01"/>
    <networkResource ref="ne_a02"/>
    <networkResource ref="ne_a03"/>
    <networkResource ref="ne_b01"/>
    <networkResource ref="ne_b02"/>
    <networkResource ref="ne_b03"/>
    <networkResource ref="ne_b04"/>
    <networkResource ref="ne_b05"/>
    <networkResource ref="ne_x01"/>
    <networkResource ref="nr_a01a02"/>
    <networkResource ref="nr_a01a03"/>
    <networkResource ref="nr_a02a03"/>
```

```
      <networkResource ref="nr_b01b03"/>
      <networkResource ref="nr_b01b04"/>
      <networkResource ref="nr_b02b04"/>
      <networkResource ref="nr_b02b05"/>
      <networkResource ref="nr_b03b04"/>
      <networkResource ref="nr_b04b05"/>
      <networkResource ref="nr_a03x01"/>
      <networkResource ref="nr_x01b03"/>
      <parameter ref="p_tg_01"/>
    </level>
    <level id="lv1" levelOfDetail="meso">
      <networkResource ref="ne_a11"/>
      <networkResource ref="ne_b11"/>
      <networkResource ref="ne_x11"/>
      <networkResource ref="nr_a11x11"/>
      <networkResource ref="nr_x11b11"/>
      <parameter ref="p_sp_01"/>
      <parameter ref="p_tp_01"/>
    </level>
  </topology>

  <coordinates>
    <geometricPositioningSystem id="gps_01" crsDefinition="epsg:4326"/>
    <geometricPositioningSystem id="gps_02" crsDefinition="epsg:25832"/>
    <linearPositioningSystem id="lps_01" name="6869" units="km" startMeasure="0.000"
endMeasure="5.000" linearReferencingMethod="absolute"/>
    <linearPositioningSystem id="lps_02" name="trackPositioningSystemInMeters"/>
    <lineCoordinate id="lco_001" positioningSystemRef="lps_01" measure="0.000"/>
    <lineCoordinate id="lco_002" positioningSystemRef="lps_01" measure="0.450"/>
    <lineCoordinate id="lco_003" positioningSystemRef="lps_01" measure="0.500"/>
    <lineCoordinate id="lco_004" positioningSystemRef="lps_01" measure="0.700"/>
    <lineCoordinate id="lco_005" positioningSystemRef="lps_01" measure="2.000"/>
    <lineCoordinate id="lco_006" positioningSystemRef="lps_01" measure="2.400"/>
    <lineCoordinate id="lco_007" positioningSystemRef="lps_01" measure="2.500"/>
    <lineCoordinate id="lco_008" positioningSystemRef="lps_01" measure="2.550"/>
    <lineCoordinate id="lco_009" positioningSystemRef="lps_01" measure="3.600"/>
    <lineCoordinate id="lco_010" positioningSystemRef="lps_01" measure="4.300"/>
    <lineCoordinate id="lco_011" positioningSystemRef="lps_01" measure="4.500"/>
    <lineCoordinate id="lco_012" positioningSystemRef="lps_01" measure="4.600"/>
    <lineCoordinate id="lco_013" positioningSystemRef="lps_01" measure="5.000"/>
  </coordinates>
```

```xml
  <operation>
   <lines>
     <line id="lin_01" lineCategory="other:CE" lineType="mainLine"
infrastructureManager="im0815">
      <linearLocation id="lin01_lloc_01" posSystemRef="lps_01">
       <linearSection id="lin01_lloc01_01" fromPos="0.000" toPos="5.000"/>
      </linearLocation>
      <aggregatedLocation id="lin01_aloc_01">
       <spot id="lin01_aloc01_01" netElementRef="ne_a11"/>
       <spot id="lin01_aloc01_03" netElementRef="ne_b11"/>
       <linearSection id="lin01_aloc01_02" netElementRef="ne_x11" fromPos="0"
toPos="1"/>
      </aggregatedLocation>
      <operationalPoint ref="opp_01"/>
      <operationalPoint ref="opp_02"/>
     </line>
    </lines>

    <operationalPoints>
     <operationalPoint id="opp_01" name="Bf Arnau">
      <spotLocation id="opp01_sloc_01">
       <spot id="opp01_sloc01_01" netElementRef="ne_a11" pos="0"/>
      </spotLocation>
      <spotLocation id="opp01_sloc_02" posSystemRef="lps_01">
       <spot id="opp01_sloc02_01" pos="0.350"/>
      </spotLocation>
      <designator register="DIDOK" entry="AARN"/>
      <propertiesOperation operationalType="station"/>
     </operationalPoint>
     <operationalPoint id="opp_02" name="Bf Cstadt">
      <spotLocation id="opp02_sloc_01">
       <spot id="opp02_sloc01_01" netElementRef="ne_b11" pos="0"/>
      </spotLocation>
      <spotLocation id="opp02_sloc_02" posSystemRef="lps_01">
       <spot id="opp02_sloc02_01" pos="4.650"/>
      </spotLocation>
      <designator register="DIDOK" entry="CSDT"/>
      <propertiesOperation operationalType="station"/>
     </operationalPoint>
    </operationalPoints>
```

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```xml
    <speedRestrictions>
     <speedRestriction id="spr_01" vMax="20" isTemporary="true">
      <linearLocation id="spr01_lloc_01">
       <linearSection id="spr01_lloc01_01" netElementRef="ne_x01" fromPos="0.4722" toPos="0.5139" dir="up"/>
      </linearLocation>
      <linearLocation id="spr01_lloc_02" posSystemRef="lps_01">
       <linearSection id="spr01_lloc02_01" fromPos="2.400" toPos="2.550" dir="up"/>
      </linearLocation>
     </speedRestriction>
    </speedRestrictions>
   </operation>

   <!-- <trackGeometry></trackGeometry> -->

   <assets>
    <bufferStops>
     <bufferStop id="bus_01">
      <spotLocation id="bus01_sloc_01">
       <spot id="bus01_sloc01_01" netElementRef="ne_a01" pos="0"/>
      </spotLocation>
      <spotLocation id="bus01_sloc_02" posSystemRef="lps_01">
       <spot id="bus01_sloc02_01" pos="0.000"/>
      </spotLocation>
     </bufferStop>
     <bufferStop id="bus_02">
      <spotLocation id="bus02_sloc_01">
       <spot id="bus02_sloc01_01" netElementRef="ne_a02" pos="0"/>
      </spotLocation>
      <spotLocation id="bus02_sloc_02" posSystemRef="lps_01">
       <spot id="bus02_sloc02_01" pos="0.000"/>
      </spotLocation>
     </bufferStop>
     <bufferStop id="bus_03">
      <spotLocation id="bus03_sloc_01">
       <spot id="bus03_sloc01_01" netElementRef="ne_b01" pos="1"/>
      </spotLocation>
      <spotLocation id="bus03_sloc_02" posSystemRef="lps_01">
       <spot id="bus03_sloc02_01" pos="5.000"/>
      </spotLocation>
```

```xml
      </bufferStop>
     <bufferStop id="bus_04">
      <spotLocation id="bus04_sloc_01">
       <spot id="bus04_sloc01_01" netElementRef="ne_b02" pos="1"/>
      </spotLocation>
      <spotLocation id="bus04_sloc_02" posSystemRef="lps_01">
       <spot id="bus04_sloc02_01" pos="5.000"/>
      </spotLocation>
     </bufferStop>
     <bufferStop id="bus_05">
      <spotLocation id="bus05_sloc_01">
       <spot id="bus05_sloc01_01" netElementRef="ne_b05" pos="0"/>
      </spotLocation>
     </bufferStop>
    </bufferStops>

    <derailers>
     <derailer id="der_01" derailSide="right">
      <spotLocation id="sloc_050">
       <spot id="sloc_050_01" netElementRef="ne_b05" pos="0.8"/>
      </spotLocation>
     </derailer>
    </derailers>

    <levelCrossings>
     <levelCrossing name="levelCrossing01" id="lcr_01"
protectionType="automaticHalfBarrier">
      <spotLocation id="lcr01_sloc_01">
       <spot id="lcr01_sloc01_01" netElementRef="ne_x01" dir="up" pos="0.6944"/>
       <gml_point id="lcr01_sloc0101_gml_01">
        <description>this is a GML point</description>
        <pos>52.123 10.456</pos>
       </gml_point>
      </spotLocation>
      <spotLocation id="lcr01_sloc_02" posSystemRef="lps_01">
       <spot id="lcr01_sloc_02_01" pos="2.500"/>
      </spotLocation>
     </levelCrossing>
    </levelCrossings>

    <platforms>
```

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```xml
      <platform id="plf_01" hasRoof="true" hasElevator="true">
       <spotLocation id="sloc_012">
        <spot id="sloc_012_01" netElementRef="ne_a11" pos="0"/>
       </spotLocation>
       <platformEdge id="ple_01" height="550" length="200">
        <linearLocation id="lloc_001">
         <linearSection id="lloc_001_01" netElementRef="ne_a01" fromPos="0.2"
toPos="0.6"/>
        </linearLocation>
       </platformEdge>
       <platformEdge id="ple_02" height="550" length="200">
        <linearLocation id="lloc_002">
         <linearSection id="lloc_002_01" netElementRef="ne_a02" fromPos="0.2"
toPos="0.6"/>
        </linearLocation>
       </platformEdge>
      </platform>
      <platform id="plf_02" hasRoof="true">
       <spotLocation id="sloc_013">
        <spot id="sloc_013_01" netElementRef="ne_b11" pos="0"/>
       </spotLocation>
       <platformEdge id="ple_03" height="550" length="200">
        <linearLocation id="lloc_003">
         <linearSection id="lloc_003_01" netElementRef="ne_b01" fromPos="0.4"
toPos="0.8"/>
        </linearLocation>
       </platformEdge>
      </platform>
      <platform id="plf_03" hasRoof="false">
       <spotLocation id="sloc_014">
        <spot id="sloc_014_01" netElementRef="ne_b11" pos="0"/>
       </spotLocation>
       <platformEdge id="ple_04" height="380" length="250">
        <linearLocation id="lloc_004">
         <linearSection id="lloc_004_01" netElementRef="ne_b02" fromPos="0.4444"
toPos="1"/>
        </linearLocation>
       </platformEdge>
      </platform>
     </platforms>
```

```xml
<signals>
 <signal name="68N2" id="sig_01" type="main">
  <spotLocation id="sig01_sloc_01">
   <spot id="sig01_sloc01_01" netElementRef="ne_a01" pos="0.9" dir="up"/>
  </spotLocation>
  <spotLocation id="sig01_sloc_02" posSystemRef="lps_01">
   <spot id="sig01_sloc02_01" pos="0.450"/>
  </spotLocation>
 </signal>
 <signal name="68N1" id="sig_02" type="main">
  <spotLocation id="sig02_sloc_01">
   <spot id="sig02_sloc01_01" netElementRef="ne_a02" pos="0.9" dir="up"/>
  </spotLocation>
  <spotLocation id="sig02_sloc_02" posSystemRef="lps_01">
   <spot id="sig02_sloc02_01" pos="0.450"/>
  </spotLocation>
 </signal>
 <signal name="68F" id="sig_03" type="main">
  <spotLocation id="sig03_sloc_01">
   <spot id="sig03_sloc01_01" netElementRef="ne_a03" pos="1" dir="down"/>
  </spotLocation>
  <spotLocation id="sig03_sloc_02" posSystemRef="lps_01">
   <spot id="sig03_sloc02_01" pos="0.700"/>
  </spotLocation>
 </signal>
 <signal name="69A" id="sig_04" type="main">
  <spotLocation id="sig04_sloc_01">
   <spot id="sig04_sloc01_01" netElementRef="ne_b03" pos="0" dir="up"/>
  </spotLocation>
  <spotLocation id="sig04_sloc_02" posSystemRef="lps_01">
   <spot id="sig04_sloc02_01" pos="4.300"/>
  </spotLocation>
 </signal>
 <signal name="69P2" id="sig_05" type="main">
  <spotLocation id="sig05_sloc_01">
   <spot id="sig05_sloc01_01" netElementRef="ne_b01" pos="0.2" dir="down"/>
  </spotLocation>
  <spotLocation id="sig05_sloc_02" posSystemRef="lps_01">
   <spot id="sig05_sloc02_01" pos="4.600"/>
  </spotLocation>
 </signal>
```

```
    <signal name="69P1" id="sig_06" type="main">
     <spotLocation id="sig06_sloc_01">
      <spot id="sig06_sloc01_01" netElementRef="ne_b02" pos="0.1111" dir="down"/>
     </spotLocation>
     <spotLocation id="sig06_sloc_02" posSystemRef="lps_01">
      <spot id="sig06_sloc02_01" pos="4.600"/>
     </spotLocation>
    </signal>
    <signal id="sig_07" name="69Va" type="distant">
     <spotLocation id="sig07_sloc_01">
      <spot id="sig07_sloc01_01" netElementRef="ne_x01" pos="0.8056" dir="up"/>
     </spotLocation>
     <spotLocation id="sig07_sloc_02" posSystemRef="lps_01">
      <spot id="sig07_sloc02_01" pos="3.600"/>
     </spotLocation>
    </signal>
    <signal id="sig_08" name="69W04Y" type="shunting">
     <spotLocation id="sig08_sloc_01">
      <spot id="sig08_sloc01_01" netElementRef="ne_b05" pos="0.6" dir="up"/>
     </spotLocation>
    </signal>
   </signals>

   <switches>
    <switch name="68W02" id="swi_01" branchingSpeed="60"
crossingAngleTangent="1/12" radiusBranchLeft="500">
     <spotLocation id="swi01_sloc_01">
      <spot id="swi01_sloc01_01" netElementRef="ne_a11" pos="0"/>
     </spotLocation>
     <spotLocation id="swi01_sloc_02" posSystemRef="lps_01">
      <spot id="swi01_sloc02_01" pos="0.500"/>
     </spotLocation>
     <switchBegin id="swi01_b">
      <spotLocation id="swi01_b_sloc_01">
       <spot id="swi01_b_sloc01_01" netElementRef="ne_a03" pos="0.1" dir="down"/>
      </spotLocation>
     </switchBegin>
     <switchEnd id="swi01_e1" course="straight" isDefaultCourse="true"
isMainTrack="true">
      <spotLocation id="swi01_e1_sloc_01">
       <spot id="swi01_e1_sloc01_01" netElementRef="ne_a01" pos="0.96" dir="up"/>
```

```
        </spotLocation>
      </switchEnd>
      <switchEnd id="swi01_e2" course="left">
       <spotLocation id="swi01_e2_sloc_01">
         <spot id="swi01_e2_sloc01_01" netElementRef="ne_a02" pos="0.96" dir="up"/>
       </spotLocation>
      </switchEnd>
    </switch>
    <switch name="69W03" id="swi_02" branchingSpeed="40" crossingAngleTangent="1/9"
radiusBranchRight="300">
      <spotLocation id="swi02_sloc_01">
       <spot id="swi02_sloc01_01" netElementRef="ne_b11" pos="0"/>
      </spotLocation>
      <spotLocation id="swi02_sloc_02" posSystemRef="lps_01">
       <spot id="swi02_sloc02_01" pos="4.500"/>
      </spotLocation>
      <switchBegin id="swi02_b">
       <spotLocation id="swi02_b_sloc_01">
         <spot id="swi02_b_sloc01_01" netElementRef="ne_b03" pos="0.92" dir="up"/>
       </spotLocation>
      </switchBegin>
      <switchEnd id="swi02_e1" course="straight" isDefaultCourse="true"
isMainTrack="true">
       <spotLocation id="swi02_e1_sloc_01">
         <spot id="swi02_e1_sloc01_01" netElementRef="ne_b01" pos="0.032" dir="down"/>
       </spotLocation>
      </switchEnd>
      <switchEnd id="swi02_e2" course="right">
       <spotLocation id="swi02_e2_sloc_01">
         <spot id="swi02_e2_sloc01_01" netElementRef="ne_b04" pos="0.32" dir="down"/>
       </spotLocation>
      </switchEnd>
    </switch>
    <switch name="69W04" id="swi_03" branchingSpeed="40" crossingAngleTangent="1/9"
radiusBranchRight="300">
      <spotLocation id="swi03_sloc_01">
       <spot id="swi03_sloc01_01" netElementRef="ne_b11" pos="0"/>
      </spotLocation>
      <spotLocation id="swi03_sloc_02" posSystemRef="lps_01">
       <spot id="swi03_sloc02_01" pos="4.550"/>
      </spotLocation>
```

```
  <switchBegin id="swi03_b">
   <spotLocation id="swi03_b_sloc_01">
    <spot id="swi03_b_sloc01_01" netElementRef="ne_b02" pos="0.0356" dir="down"/>
   </spotLocation>
  </switchBegin>
  <switchEnd id="swi03_e1" course="straight">
   <spotLocation id="swi03_e1_sloc_01">
    <spot id="swi03_e1_sloc01_01" netElementRef="ne_b05" pos="0.936" dir="up"/>
   </spotLocation>
  </switchEnd>
  <switchEnd id="swi03_e2" course="right" isDefaultCourse="true" isMainTrack="true">
   <spotLocation id="swi03_e2_sloc_01">
    <spot id="swi03_e2_sloc01_01" netElementRef="ne_b04" pos="0.68" dir="up"/>
   </spotLocation>
  </switchEnd>
 </switch>
</switches>

<trainDetectionElements>
 <trainDetectionElement id="tde_01" type="axleCounter">
  <spotLocation id="sloc_040">
   <spot id="sloc_040_01" netElementRef="ne_a01" pos="0.96"/>
  </spotLocation>
 </trainDetectionElement>
 <trainDetectionElement id="tde_02" type="axleCounter">
  <spotLocation id="sloc_041">
   <spot id="sloc_041_01" netElementRef="ne_a02" pos="0.96"/>
  </spotLocation>
 </trainDetectionElement>
 <trainDetectionElement id="tde_03" type="axleCounter">
  <spotLocation id="sloc_042">
   <spot id="sloc_042_01" netElementRef="ne_a03" pos="0.1"/>
  </spotLocation>
 </trainDetectionElement>
 <trainDetectionElement id="tde_04" type="isolatedRailJoint">
  <spotLocation id="sloc_043">
   <spot id="sloc_043_01" netElementRef="ne_b03" pos="0"/>
  </spotLocation>
 </trainDetectionElement>
 <trainDetectionElement id="tde_05" type="isolatedRailJoint">
  <spotLocation id="sloc_044">
```

```
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   </trainDetectionElement>
   <trainDetectionElement id="tde_08" type="isolatedRailJoint">
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    </spotLocation>
   </trainDetectionElement>
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 </assets>

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  <trackGauge id="p_tg_01" trackGauge="1435"/>
  <electrification id="p_el_01" voltage="50" frequency="16.7"/>
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  <trainProtection id="p_tp_01" trainProtectionSystem="Indusi"/>
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</infrastructure>
</railML>
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