IFC 4.3 Implementation & Validation Report

IFC Rail Part

Overview and result of Unit Tests in implementation and validation of IFC Rail Phase 2 project. It is also a report for Work Package 1 (WP1) of IFC Rail Phase 2 project.

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1 Introduction

This document is built to summarize the organization, process, scope and results of Work Package 1 (WP1) of IFC Rail Phase 2 project. It is part of the official deliverables of the report for implementation and validation of IFC 4.3, as shown in **Error! Reference source not found.** below. Please refer to the *I FC 4.3 Deployment Report: Executive Summary – Rail & Infra* for further details.

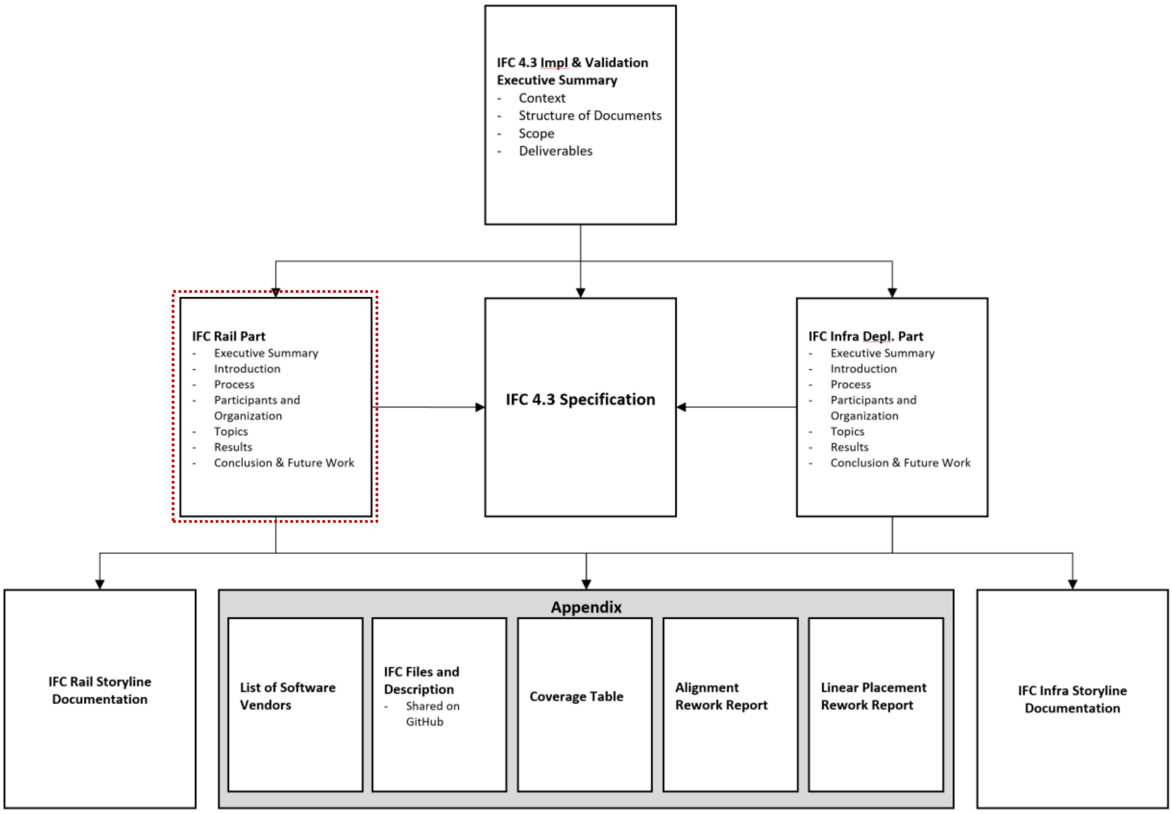

Figure 1 The position of this document in the structure of deliverables

This document reports the work of implementation and validation of IFC 4.3 through Unit Tests managed by IFC Rail project. These Unit Tests are designed to make sure that IFC 4.3 is a valid standard that can be implemented and will be correctly implemented by software vendors to meet the fundamental requirements of railway business. reports the scope and timeline of this work (Chapter 1), organization and software vendor participation (Chapter 2), process and tooling (Chapter 3), unit test topics and cases (Chapter 4), results of unit tests (Chapter 5) and future work (Chapter 6). According to the standardization procedure of bSI shown in **Error! Reference source not found.**, this p rocess is a necessary step to bring a bSI Candidate Standard to a Final Standard status. By reporting the results of Unit Tests performed by software vendors, this document aims to support the voting process of IFC 4.3 Specification submitted to the Standard Committee Executive members.

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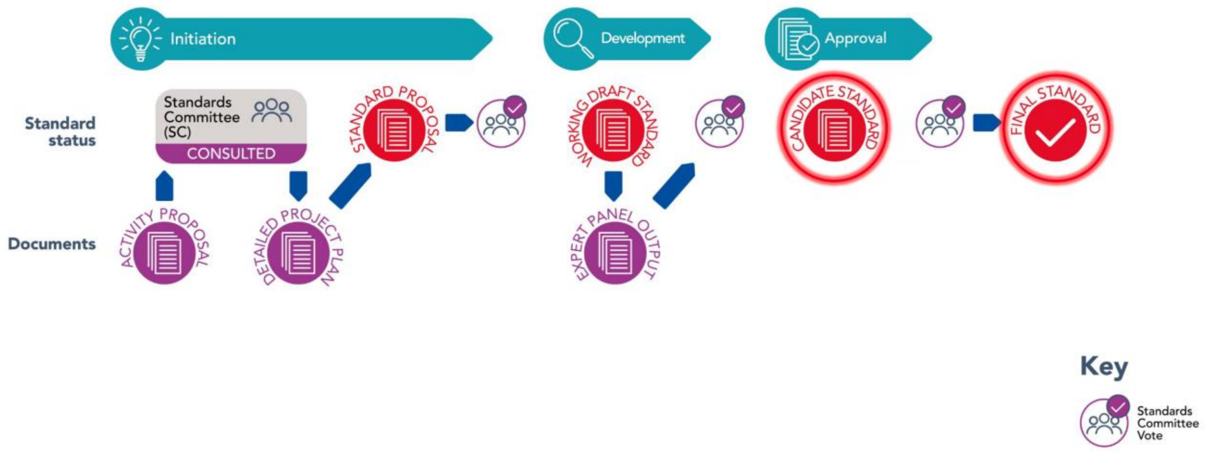

Figure 2 Standardization process of buildingSMART

1.1 Scope

This report focuses on the process and result of WP 1 of IFC Rail Phase 2. In WP 1 of IFC Rail Phase 2 project, Unit Tests focus on the new entities and fundamental concepts extended since IFC 4.1, especially on the concepts that are extended by the IFC Rail project in 2018-2019. The focused topics of Unit Tests are listed as follows:

- *Alignment with Cant (AWC)*
- *Linear Placement (LP)*
- *Swept Area Solid (SAS)*
- *Railway Spatial Structure (RSS)*
- *System Breakdown Structure (SYS)*
- *Port Connectivity (PCC)*

Besides these fundamental concepts, there is one more topic labelled as:

- *Domain Physical Elements (DPE)*

This topic contains integration tests that combines multiple fundamental concepts. More importantly, it aims to apply the proper entities and predefined types standardized in railway domains including Track, Energy, Signalling and Telecommunication.

Details of each topic are reported in Chapter 4.

1.2 Timeline

The starting point for test and implementation is IFC4.3_RC1, which was published by bSI in April 2020. Till the end of June 2021, the IFC Rail project has organized the project team with software vendors and collaborated with Infra Extension Deployment project to manage the tests. During this process, the collected feedback has resulted in updating of the standard . The key events and milestones in the timeline are listed in Figure 3 and Table 1, which correspond to organization of meeting series and publications of the standard as release candidates.

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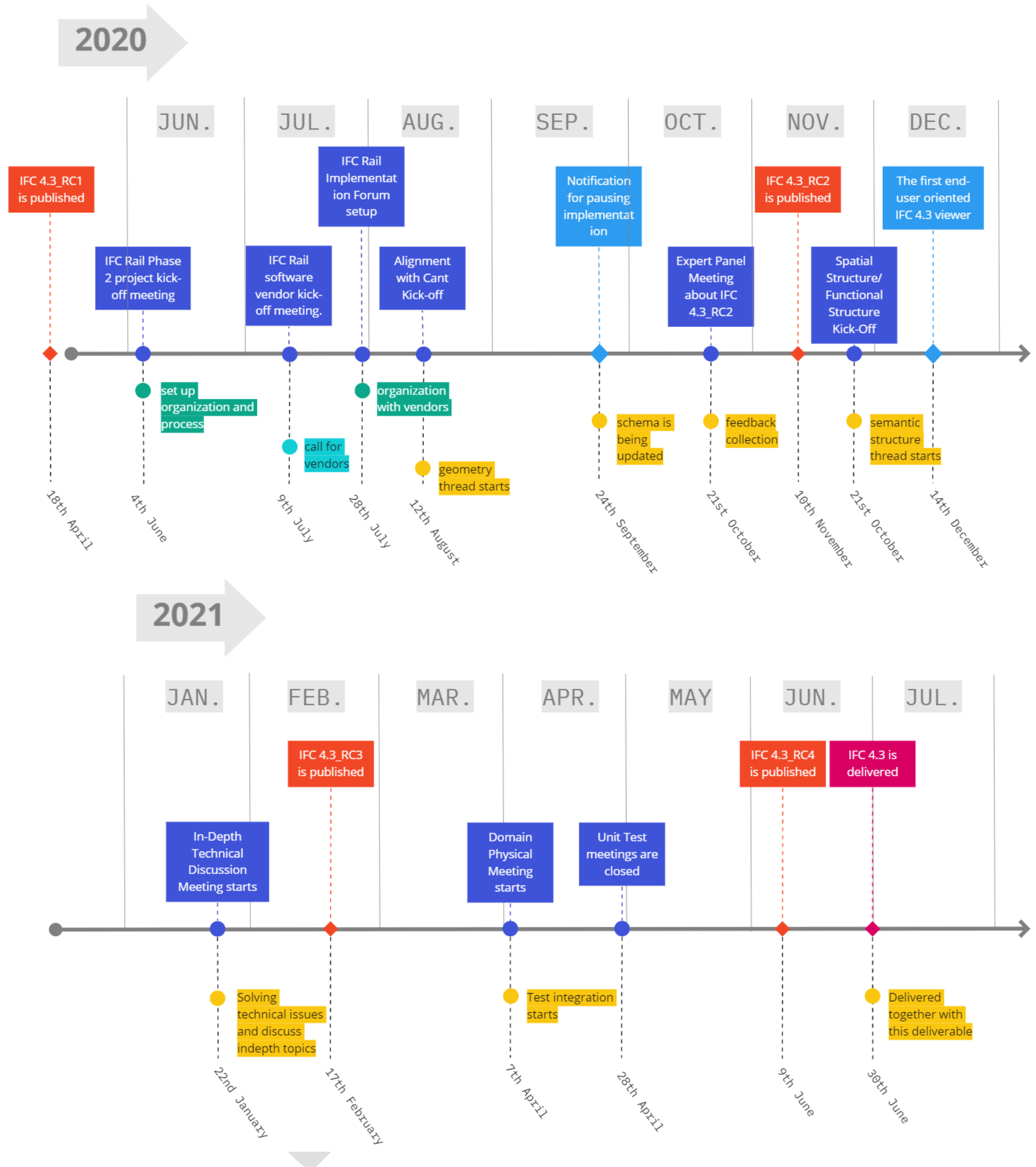

Figure 3 Timeline with key milestones and events in the IFC Rail Phase 2 project regarding test and implementation

Date	Milestone & Key Event
April 18th 2020	IFC 4.3_RC1 is published (in the timeline of IFC Rail Phase 1)
June 4th 2020	IFC Rail Phase 2 Project kick-off meeting
July 9th 2020	IFC Rail software vendor kick-off meeting. Unit Tests work is broken down by Topics.
July 28th 2020	IFC Rail Implementation Forum setup.

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August 12th 2020	Alignment with Cant Kick-off – the first thread of Unit Test meetings started
September 24th 2020	Notification for pausing implementation because of schema update
October 21st 2020	Joint Expert Panel meeting with Infra Extension Deployment project and software vendors about IFC 4.3_RC2
November 10th 2020	The IFC 4.3_RC2 is published
November 25th 2020	Railway Spatial Structure and Functional Structure kick-off meeting – the second thread of Unit Test meetings started
January 22nd 2021	The weekly meeting "Indepth Technical Discussion about IFC 4.3" officially started
February 17th 2021	IFC_4.3_RC3 is shared with software vendors
April 7th 2021	Domain Physical Elements meeting started – start to integrate unit test topics together with classification of railway elements
April 28th 2021	Unit Test meetings are closed and started IFC file checking
June 30th 2021	The milestone for delivering this document together with IFC 4.3 and other deliverables to bSI

Table 1 Date and description of milestones and key events in the timeline

2 Organization and Participation

The IFC Rail Phase 2 project is governed under buildingSMART Railway Room. It is supported by 10 stakeholders, which are national railway and infrastructure design and management companies or projects from 8 countries in Europe and Asia. They are listed as follows:

- Austria: ÖBB-Infrastruktur AG
- China: CRBIM
- Denmark: Banedenmark
- Finland: FTIA Väylävirasto (formerly Liikennevirasto)
- France: MINnD
- France: SNCF Réseau
- Italy: RFI
- Norway: BANE NOR
- Sweden: Trafikverket
- Switzerland: SBB Infrastruktur

2.1 Overall project organization structure

The overall organization structure of IFC Rail Phase 2 Project is described as follows:

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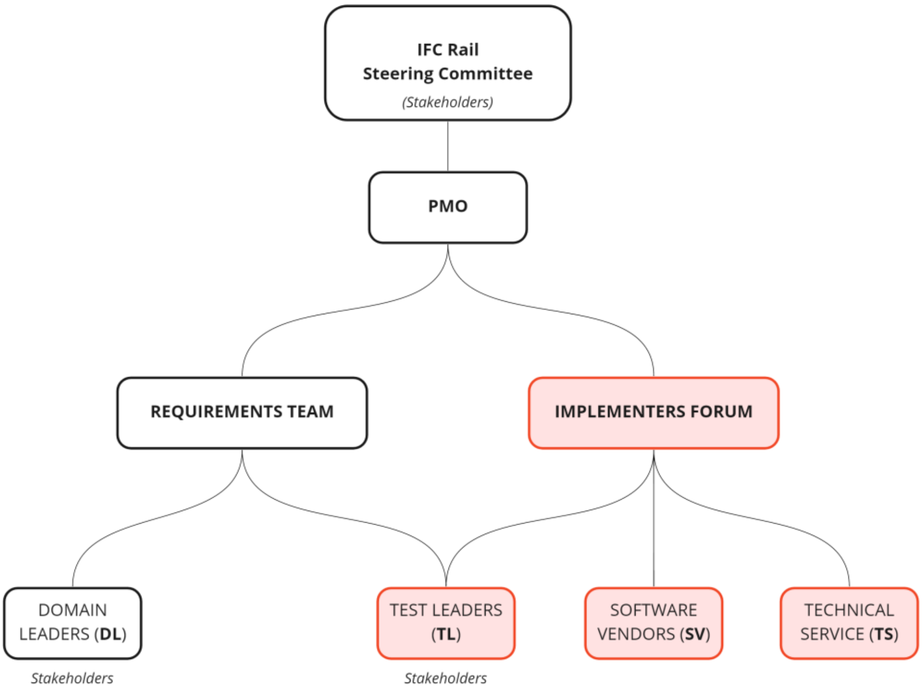

Figure 4 IFC Rail Phase 2 Organization

- **Steering Committee**: the Steering Committee of IFC Rail Phase 2 project is staffed by representatives of project stakeholders.
- **Project Management Office (PMO)**: PMO is under the governance of Steering Committee, taking charge of project progress, timeline, budget and resources.
- **Requirements Team**: staffed by Domain Leaders and Test Leaders (one per Storyline), who take charge of defining storylines, and providing requirements and datasets.
- **Domain Leaders Group**: inherit the organization from IFC Rail project in 2018-2019. Each railway domain including Track, Energy, Signalling and Telecommunication has two Domain Leaders, who take charge of handling change requests and any updates that related to the domain in the standard.
- **Test Leaders Group**: is staffed by railway domain experts from project stakeholders. They are the daily representatives of stakeholders in the project. Each Test Leader owns a Storyline, which is a realistic process to be tested in the project. From Storylines, essential atomic topics are identified and derived as Unit Tests for software vendors to test. A Test Leader may have a team staffed by domain experts who support him/her to define the requirements or process in the Storyline or Unit Tests.
- **Implementers Forum**: it is the organization onboarding and managing communication with software vendors. It is directly related to all the activities performed by software vendors including Unit Test, which is the subject of this document. The Implementers Forum is staffed by representatives from Software Vendors and Technical Service from the project. Test Leaders also participate in the Implementers Forum to provide requirements and monitor the progress. Details about Implementers Forum are described in Chapter 2.2.
- **Technical Service**: staffed by technical experts who support Test Leaders to formalize requirements, and support software vendors for implementation. Technical Service is the

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organization which takes charge of Unit Test work with software vendors. They also collect feedback in test processes and update the standard if necessary.

- **Software Vendors**: perform tests and share the results with the project. Software Vendors also report issues or give feedbacks to the project. Details about participated software vendors are listed in Chapter .

2.2 IFC Rail Implementers Forum (Rail-IF)

Part of the challenge for a bSI Project is to get its work validated, through software, during the development of the standard. The IFC Rail project responds to this challenge is the IFC Rail Implementers Forum (Rail-IF) and has its proper place inside the *demand-driven standard* philosophy of bSI (see **Error! Reference source not found.**). The IFC Rail Implementers Forum is the organization onboarding and managing communication with software vendors, during the testing and validation phase of the IFC Rail Project – Phase 2. It is the organization that is directly related to the topic of this document.

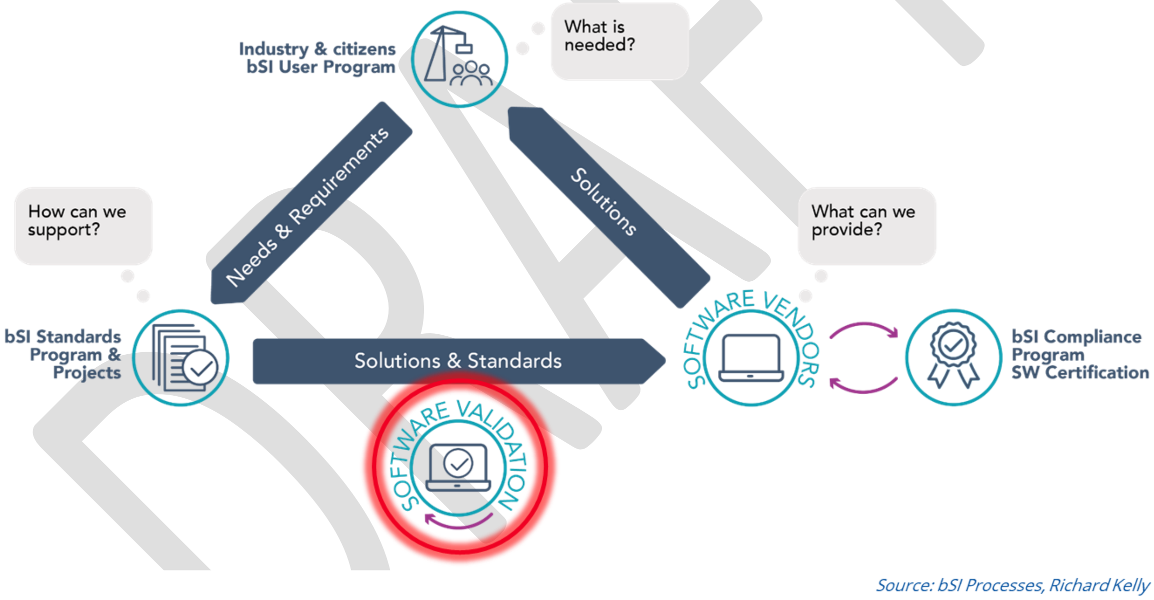

Figure 5 Position of the IFC Rail Implementers Forum in the processes of bSI

The Rail-IF has been first of all a big opportunity, for everyone involved in the Project, to experiment with the newly created Candidate Standard – to fine-tune it and make it Final. There is no other environment where Software Vendors can get in contact both with railway stakeholders (and their business requirements) and with the IFC technical experts (and their knowledge of IFC 4.3 standard).

2.2.1 Participation

The IFC Rail Implementers Forum is a global initiative, involving 10 railway stakeholders of the project and 29 software vendors across 16 countries. **Error! Reference source not found.** captures the participation of the Rail IF and its cross-continental coverage.

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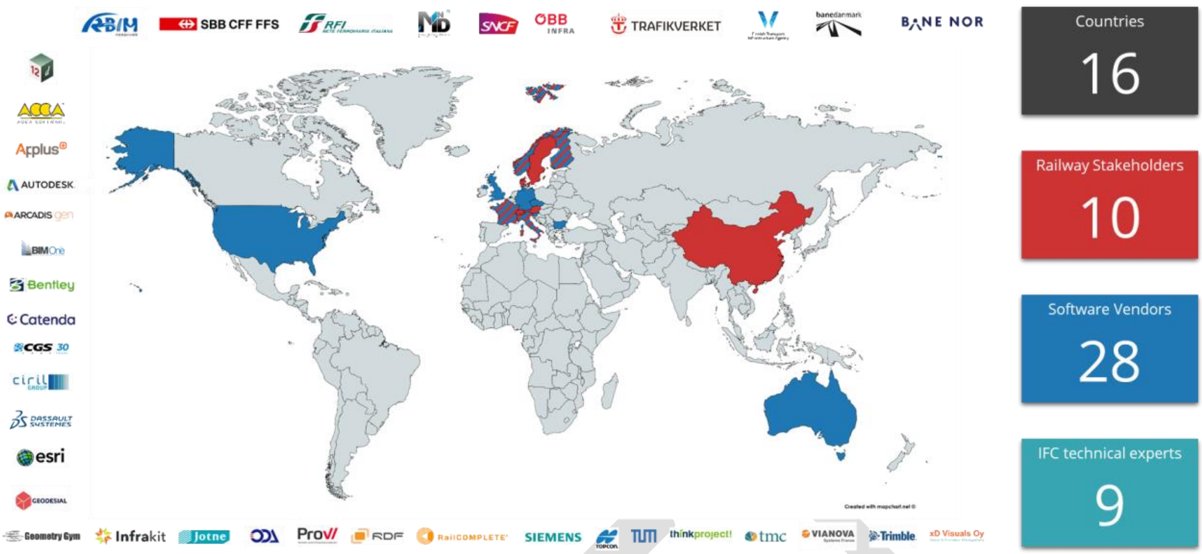

Figure 6 Participation of IFC Rail Implementers Forum

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In total, there are 29 software vendors from Europe, US and Australia that have participated in this project. They are listed as follows:

- 12d Solutions
- A+S
- ACCA Software
- Arcadis Gen
- Autodesk
- Bentley Systems
- BimOne
- Catenda AS
- CGS Labs d.o.o.
- Cirilgroup
- Dassault Systems
- Eris
- GEODESIAL GROUP
- GeometryGym
- Infrakit
- Jotne
- Open Design Alliance (ODA)
- ProVi
- RailCOMPLETE
- RDF Ltd.
- Siemens Mobility GmbH
- Technische Universität München
- Thinkproject
- Topcon Technology Finland
- Track Machines Connected GmbH

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- Trimble
- Trimble-Vianova
- VARS BRNO a.s.
- xD Visuals Oy

Introduction of each software vendor is listed in Appendix A.

2.2.2 Objectives and responsibilities

The Rail-IF has the following objectives:

- Provide processes and tools to support the testing activities;
- Coordinate all the parties involved in this phase;
- Give visibility of the testing activities and results, across the actors of the Forum;
- Inform the Stakeholders' Steering Committee about the overall performance of the Forum.

As requested by the Stakeholders of the Project, the activities of the Forum are monitored through some **key performance indicators** (KPIs), to derive the **level of engagement** and the **level of success**. Thanks to the above mentioned setup, the Forum has been able to consistently produce:

- a monthly report to the Steering Committee of the Project;
- a final report for bSI (see Chapter 5.1).

2.3 Meeting structure

With more than one hundred people involved in the project, and a wide variety of backgrounds, the IFC Rail project pursued its objectives through a set of well defined processes and a robust plan of regular meetings. The diagram below counts the number of meetings (per category of meeting) held by the project, from its kick-off (4th June 2020) till the time of writing (end of June 2021). In twelve months, more than 160 meetings have taken place.

Meetings that are directly related to Unit Tests are described as follows. The right-hand half of the diagram in Figure 7 Distribution of meetings of IFC Rail project captures these meetings:

- **18 Rail Implementers Forum meetings**, every three weeks;
- **27 Indepth Technical Discussions about IFC 4.3**, every week;
- **19 Thread 1 Unit Test Topic** meetings (AWC, LP, SAS), by-weekly;
- **9 Thread 2 Unit Test Topic** meetings (RSS, SYS, PCC, DPE), by-weekly;
- **7 Infra liaison** meetings.

For a total of 80 meetings (49% of the total).

These meetings are structured to serve the goal of testing the IFC 4.3 standard (see Figure 8):

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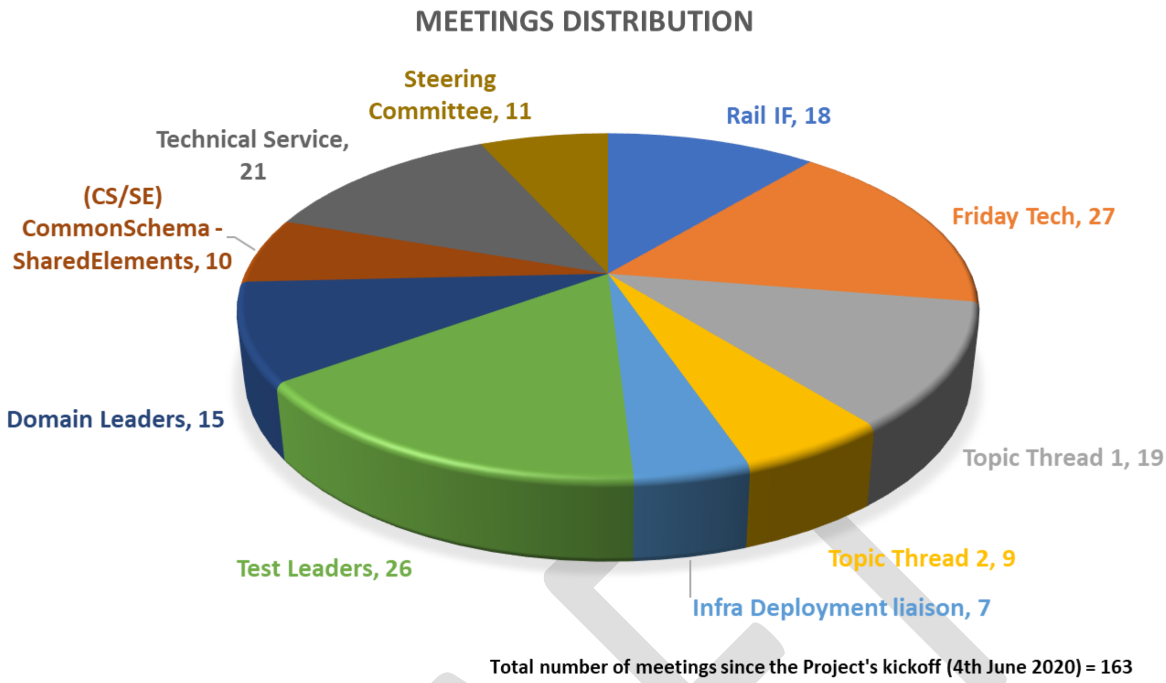

Figure 7 Distribution of meetings of IFC Rail project

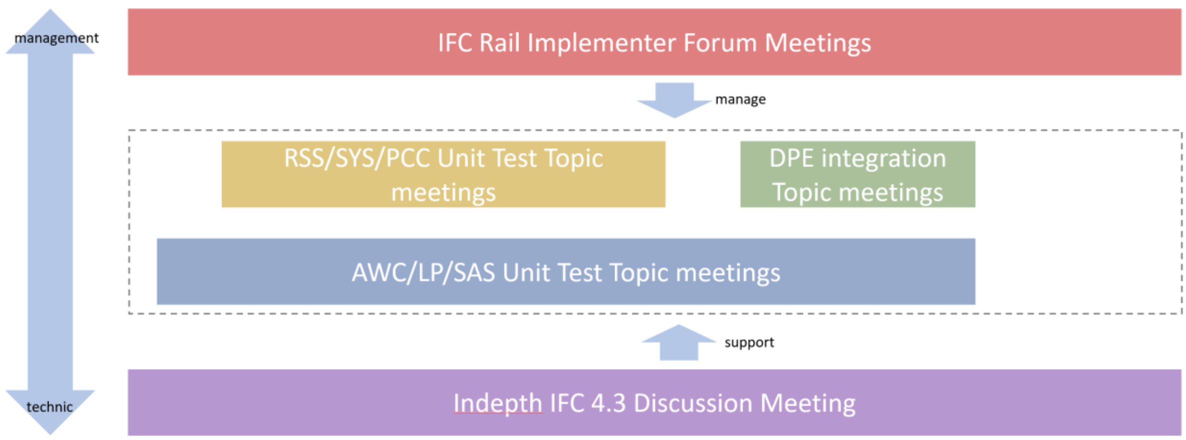

Figure 8 The structure of meetings directly related to Unit Test activities

- **IFC Rail Implementers Forum Meeting**: focuses on coordination and communication with software vendors to identify common interests, communicate general progress and facilitate organizations. It is meeting on high level that manages testing activities performed by software vendors.
- **Unit Test Topic Meetings**: focus on specific topics and cases for Unit Tests. Unit Test Topic meetings are grouped into three series of meetings.

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- **AWC/LP/SAS Topic meeting**: focuses on fundamental geometry and positioning topics including Alignment with Cant (AWC), Linear Placement (LP) and Swept Area Solid (SAS).
- **RSS/SYS/PCC/DPE Topic meeting**: focuses on essential semantic structural topics including Railway Spatial Structure (RSS), System Breakdown Structure (SYS) and Port Connectivity (PCC). This meeting is organized every other since November 25th 2020 till March 24th 2021.

- **In-depth Technical Discussion on IFC 4.3**: focus on technical issues identified in the implementation of IFC 4.3, participated by software vendors and technical services from IFC Rail and IFC Infra Extension Deployment project.
- **Infra liaison meeting**: focus on planning and process for updating the IFC 4.3 standard based on collected issues.

3 Process

3.1 High Level Process

The high-level structure of all the work is established through the V-model to bridge Domain Experts and Software Vendors and clarify all the terms used. The structure is illustrated in Figure 9Figure 9.

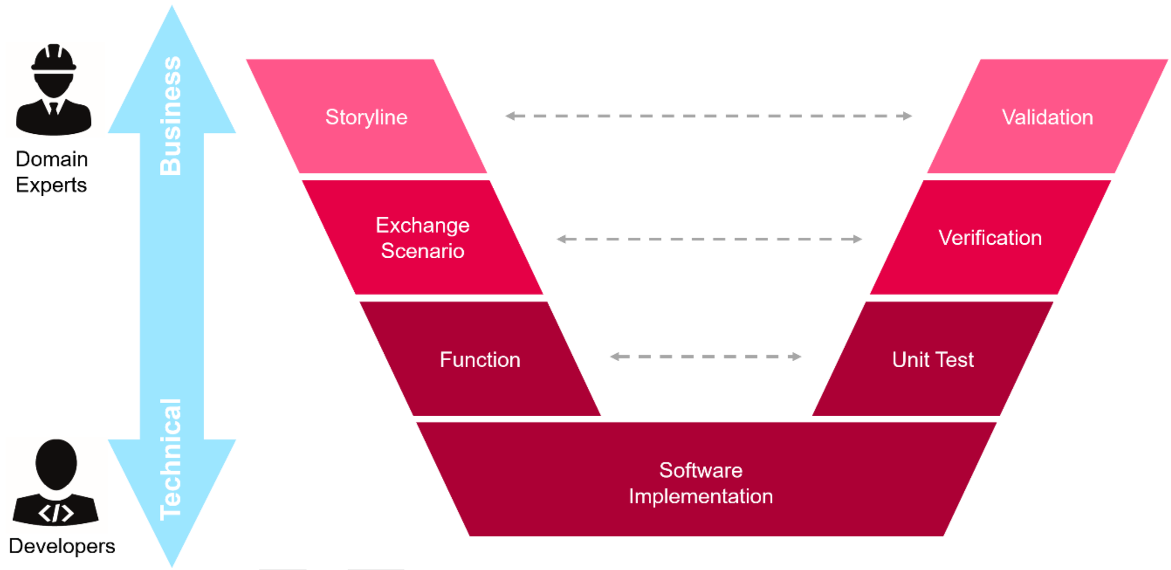

Figure 9 The V&V model for the high-level structure of the work in the entire process

- A Storyline is a realistic process in a railway project, that consists of one or more Exchange Scenarios.
- An Exchange Scenario can support one or more Use Cases.
- A Use Case may be supported by one or more Exchange Scenarios.
- An Exchange Scenario covers one or more Unit Test Topics that can be performed by IFC 4.3.
- A Unit Test Topic can be covered by one or more Exchange Scenarios.
- The evaluation whether IFC 4.3 can meet the requirement of a Unit Test Topic is conducted by Unit Tests.

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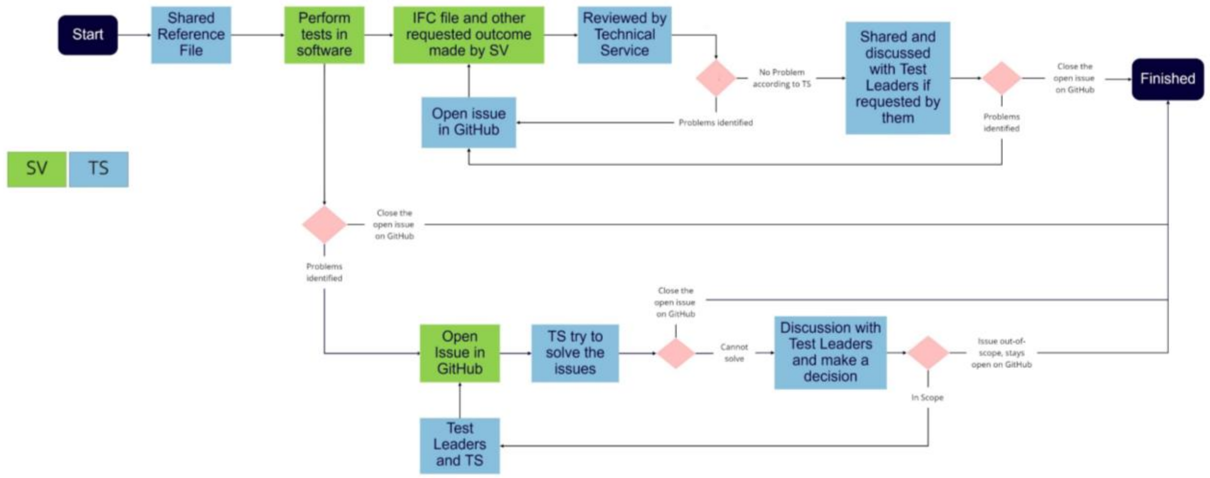
- The evaluation whether IFC 4.3 can support the requirements defined for an Exchange Scenario is conducted by Verification.
- The evaluation whether IFC 4.3 can support operation in a Storyline is conducted by Validation.

3.2 Unit Test Acceptance Process

The general purpose of Unit Tests is to improve the standard and clarify the way for implementation. In general, each Unit Test aims to let one or more software vendors to create at least one IFC file based on a dataset or requirements. During this process, software vendors could identify issues to report. The produced IFC files can be reviewed by the project team or other vendors to identify additional issues.



The acceptance process of a Unit Test is described as follows:

1. For a targeted Unit Test Topic (see Chapter 4), a dataset is prepared by a Test Leader, Technical Service or a Software Vendor. This Dataset is documented to describe the purpose, general content and specific requirements for creating IFC files. In principle, all the files in the dataset should be in open format that can be processed by any software vendors.
2. Based on the prepared dataset, an IFC reference file is created. This task is managed by a Technical Service member, who creates the IFC reference file or select an IFC file from the ones produced by software vendors (see Step 3).
3. In parallel with Step 2, software vendors are encouraged to create IFC files and other requested outcomes from the Unit Test.
4. All the created IFC files are shared with all project members and software vendors. A software vendor is encouraged to review files created by other vendors by importing them.
5. All created IFC files from software vendors are reviewed by Technical Service and are automatically checked against the IFC EXPRESS schema and additional agreements on the standard. If requested, Test Leaders can review the file to check if there are any issues.

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6. During the Step 2, 3, 4 and 5, issues can be created by software vendors, Technical Service members or Test Leaders in the form of GitHub issues. The issues could be related to standards, agreements for implementation or specific cases or files.
7. An IFC file is accepted if all relevant issues on GitHub related to the file are closed and the file has passed the checking process.
8. A Unit Test is accepted if at least one IFC file created by a software vendor for the Unit Test is accepted.

3.3 IFC File Checking Process

The created IFC files are checked against the schema and agreements made in the testing Phase. The checking considers three aspects of create IFC files:

- Schema compliance checking
- Semantic structure of the file
- Geometry consistency

For some specific cases, thorough comparisons between the created IFC files and additional data generated from legacy databases or parallel implementations are also executed.

Due to the early phase of implementation and complexity of the tested topics, there is no one tool alone can be used to check IFC files. This project uses a set of tools to

3.4 Tooling

3.4.1 GitHub

GitHub is used as the major working environment for documenting Unit Test Topics and cases, sharing results, and collecting issues. Three GitHub repositories are set up and shared with software vendors. They are listed in Table 2.

Repo. Name	Access	Description
IFC Rail Unit Test	private, shared with software vendors	The main working environment for sharing and maintaining Unit Test materials and results.
IFC Rail Unit Test Reference Code	private, eventually public	The repository for sharing some open source code for producing or checking IFC files. This repository is also used to share IFC production schema subjected for testing.
IFC Rail Sample Files	public	The repository for publishing results of validated IFC files produced in IFC Rail project, which is one of the major outcomes of testing and implementation.

Table 2 GitHub repositories established in the project

As the main working environment for sharing test materials and results, the repository is structured as follows:

- IFC Rail Unit Test repository

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- **Topic folder**: folder for Unit Test Topic, named by the topic name, e.g. 1_Alignment_with_Cant (AWC).
    - **Unit Test folder**: folder for Unit Test case, named by e.g. UT_AWC_1
        - **Dataset**: folder for the input dataset for producing IFC files
        - **IFC reference files**: folder for IFC reference files managed by the project
        - **IFC files from software vendors**: folder for IFC files from software vendors
            - **Software vendor folder**: each software vendor who produce IFC files make their own folder.

1_Alignment with Cant (AWC)	Initialisation of Folder structure for Alignment Geometry comparison ...	24 days ago
2_Linear placement (LP)	Correction to dataset LP2 / Broken chainage	2 months ago
3_Swept Area Solid (SAS)	Update README.md	2 months ago
4_Railway Spatial Structure (RSS)	Finalize UT_RSS_5 (#109)	11 days ago
5_System Breakdown and Usage (SYS)	Update UT_SYS_Overview.md	last month
6_Port and Connectivity (PCC)	UT_PCC_1: MultiDuct System with topology (#101)	3 months ago
7_Domain Physical Elements (DPE)	correct wrong directory	last month

Figure 10 Screenshot of the IFC Rail Unit Test github repository that lists all the Topic folders.

Due to the policy of project stakeholders for data security, this repository is a private repository that shared with software vendors who participated in this project. For all the datasets provided by stakeholders, these intellectual property (IP) policies apply:

- The IP of the dataset is entirely owned by the stakeholder
- The dataset is provided and can be used only for the purpose of testing to implement the IFC 4.3 standard by software vendors
- Any other utilization of the dataset beyond the scope of the implementation of the IFC Rail project needs prior written approval of the IP owner of the Data
- In course of performing the services of the tests or providing advice pre-existing invention, discovery, original works of authorship, development, improvements, trade secret, concept, or other proprietary information or intellectual property right owned by the software developer who performs the tests are not affected and remain in the ownership of the software developer

These policies only apply to datasets provided by project stakeholders. All the results of Unit Tests in the form of IFC 4.3 files and other outcomes are published in the IFC Rail Sample Files repository.

3.4.2 Tools for creating IFC files

For producing IFC reference files, Technical Service of project team have used a set of tools based on skillset of each member. They are listed as follows:

- IfcOpenShell: open source library that provides a Python programming interface and a late binding approach to quickly adapt to the updates in the IFC EXPRESS schema
- IfcEngine: IFC geometry engine provided by RDF.Ltd that can be used to create IFC files
- GeometryGym: library provided by GeometryGym that has an open source version, which can be used to create IFC files

Besides these third-party tools for creating IFC files, the project has provided a tool to create geometry of alignment based on design parameters that are defined in the semantic layer of IFC. The source code of this tool is shared on IFC Rail Unit Test Reference Code.

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3.4.3 Tools for checking IFC files

3.4.3.1 IFCCheckingTool

The IFCCheckingTool developed by Karlsruher Institut für Technologie (KIT) is used by the project team to check the produced IFC files against the IFC EXPRESS schema. It is an analysis tool for checking syntactic correctness of IFC data. It has implemented the EXPRESS language according to ISO 10303-11 and supports all aspects including Where rules and Functions in the IFC schema, which provides reliable checking results. For each major updates as release candidate of the standard, this tool is updated by KIT to adapt.

3.4.3.2 BimTester

The BimTester is extended to encode some additional rules on top of the IFC EXPRESS schema. This tool was chosen by the project team for a few reasons:

- It provides a natural language like user interface that could be configured by domain experts;
- It is possible to customize rules based on the user interface;
- It is open source and is based on IfcOpenShell, which provides a Python programming interface to extend rules with minor efforts and a late binding approach to quickly adapt to updates in the IFC EXPRESS schema.
- This tool generates HTML reports

Due to the large amount of people with different backgrounds of this project, these features can facilitate communications between different groups of people. The rules implemented by this tool are based on agreements made with software vendors, some of them are formalized as mvdXML concept template that are documented in the IFC 4.3 specification. Chapter **Error! Bookmark not defined.Error! Reference source not found.** lists details of these rules.

3.4.3.3 IFC Alignment-based Geometry Checker

As a specific concept in the railway and linear infrastructure domains, alignment is fundamental for geometry and positioning information. This project has provided a checker to check basic rules for geometry information of alignment. Details of these rules are reported in Chapter **Error! Bookmark not defined.Error! Reference source not found.**. The source code of this checker is published in the Github repository IFC Rail Unit Test Reference Code.

3.4.4 IFC Viewers

IFC viewers are useful for manual checking of IFC files and facilitate reviewing processes handled by domain experts. The project team have used two viewers provided by software vendors: 1) the IFC viewer provided by RDF.Ltd; 2) the usBIM viewer provided by ACCA software. Both of the viewer are being updated timely during the test of implementation phase. Figure 11 shows a screenshot of the usBIM viewer.

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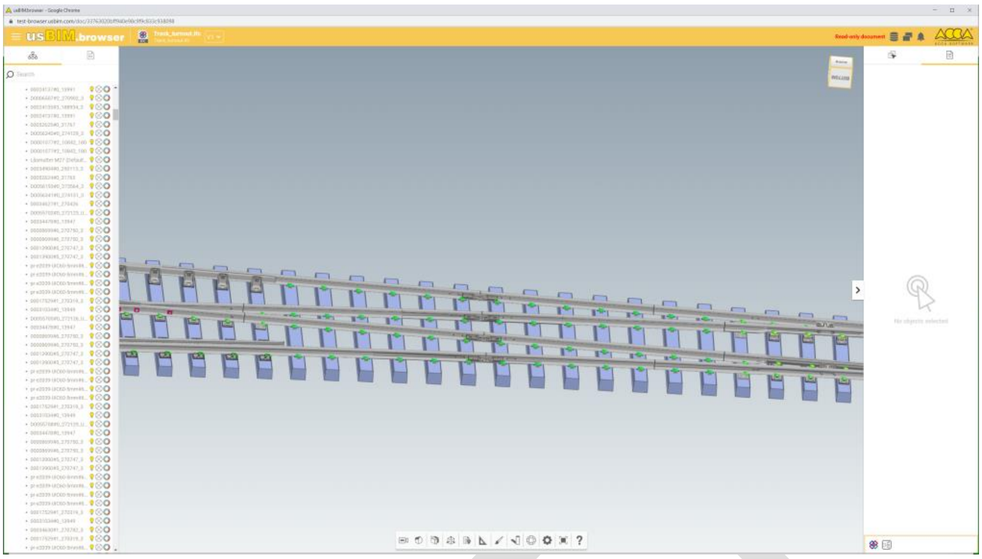

Figure 11 A screenshot of the usBIM viewer developed by ACCA software

4 Topics and Cases

As briefly described in Chapter 1.1, seven topics are focused in Unit Tests. Each topic has a list of Unit Tests that provided from different parties. Since there are some conceptual overlaps, considering timeline of the project and necessity for acceptance of the IFC 4.3 standard, they are prioritized based the following principles:

- Unit Tests that are testing new concepts (that can be formalized as IFC concept templates) defined or required in IFC 4.3 are in Priority 1.
- Unit Tests that are testing new concepts defined or required in IFC 4.3, but are more comprehensive (typically cases that covering many domain physical elements) are in Priority 2.
- Unit tests that are testing existing validated concepts in IFC or testing functionalities of software are in Priority 3. They will only be processed after Priority 1 and 2 are finished.
- If there are more than one cases covering the same new concepts in IFC, only one of them is selected into Priority 1 or 2, taken into account the balance of project stakeholders.

4.1 Alignment with Cant (AWC)

4.1.1 Intent

The Unit Tests associated to this Topic are meant to prove the possibility to parametrically represent and exchange the information of railway alignment using IFC. As a specific concept in the railway domain, cant parameters are covered in this topic, which defines the difference and change rate in elevation between the two rails. The Unit Tests shall cover the following scenarios:

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- Vertical alignment measurement
  - Vertical alignment is measured from track center line
  - Vertical alignment is measured from head of the lower rail
  - Vertical alignment is measured from bottom of the lower rail
- Horizontal alignment
  - Line segment, segment with no curvature
  - Circular arc, segment with constant curvature
  - Clothoid, segment with changed curvature that has linear change rate
  - Cubic, the approximation of clothoid
  - High performance transition bend, segment with changed curvature that has non-linear change rate, including Helmert curve, Sine curve, Viennese bend, Cosine curve and Bloss curve,
- Vertical alignment
  - Constant gradient, segment that has constant gradient
  - Circular arc, smooth transition between segments that have constant gradient, represented as a circular arc segment
  - Clothoid, smooth transition between circular arc and constant gradient
- Cant alignment
  - Constant cant, segment that has constant cant, which is usually aligned with Line segment or circular arc on horizontal alignment
  - Linear transition, segment that has linear transition, which is usually aligned with clothoid on horizontal alignment
  - Cant segment correspond to high performance transition bend

There are 9 Unit Tests documented for testing, covering different aspects of this topic in IFC. The Datasets are mainly provided by stakeholders of the project. Since Alignment with Cant is the most fundamental topic that has impact for the entire digitalization of railway, most of the Unit Tests are in Priority 1. Besides, in order to have complete coverage of transition bends, a set of small synthetic cases are defined, which are documented as UT_AWC_0.

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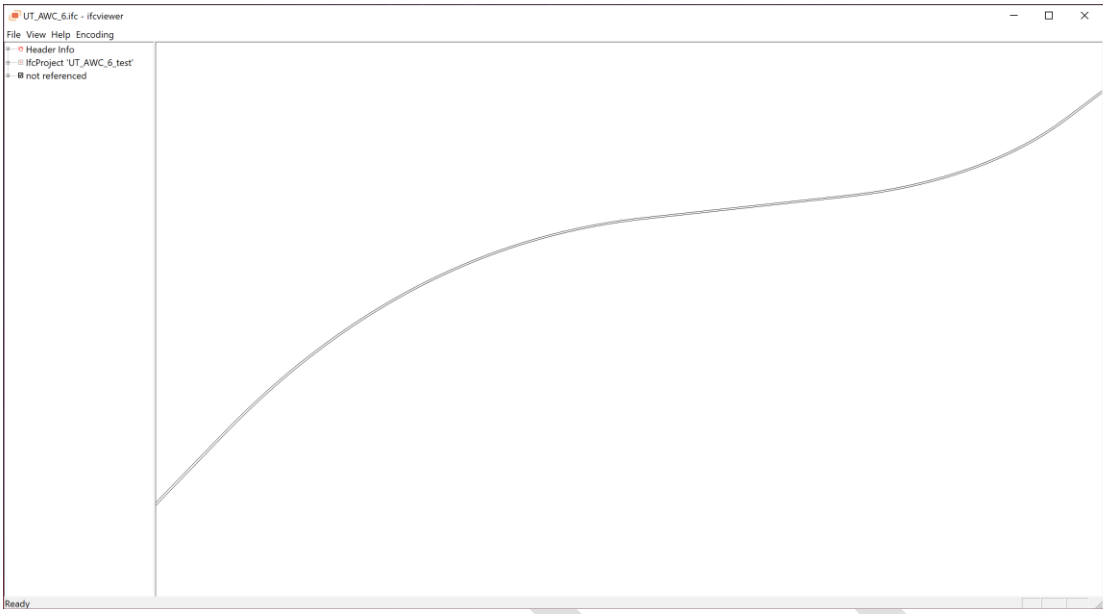

Figure 12 Example of an AWC case (UT_AWC_6); Double alignments with sine curve transitions

4.1.2 Associated Unit Tests

The overview of Unit Tests is described in Table 3.

ID	Priority	Provider	Unit Test Name
UT_AWC_0	1	Technical Service	Synthetic Test Cases for Transition Bends
UT_AWC_1	1	SBB	Alignment with Center Line Vertical Measurement
UT_AWC_2	1	SNCF	Alignments with Off-camber
UT_AWC_3	1	FTIA	Alignments at Railway Station
UT_AWC_4	1	RFI	Alignment with Clothoid
UT_AWC_5	3	RailCOMPLETE	Alignment with Parabola Vertical
UT_AWC_6	1	CRBIM	Alignment with Sine Transition
UT_AWC_7	1	RFI	Alignment with Cubic Transition
UT_AWC_8	2	FTIA	Alignment with Helmert Curve
UT_AWC_9	2	OEBB	Alignment with Vienese Bend

Table 3 Priority overview of Unit Test cases in Alignment with Cant

4.1.3 Unit Test coverage and IFC scope

The coverage of each case is detailed in Table 4.

	Concepts	UT_AWC_0	UT_AWC_1	UT_AWC_2	UT_AWC_3	UT_AWC_4	UT_AWC_5	UT_AWC_6	UT_AWC_7	UT_AWC_8	UT_AWC_9
General	Alignment layout breakdown	X	X	X	X	X	X	X	X	X	X
	Vertical measured in center line		X								
	Vertical measured in lower rail head			X		X	X	X	X		X

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	Vertical measured in lower rail bottom				X					X	
	Properties of segments			X	X	X					
Horizontal layout	Straight Line	X	X	X	X	X	X	X	X	X	
	Circular Arc	X	X	X	X	X	X	X	X	X	
	Clothoid	X	X	X	X	X	X				
	Cubic	X							X		
	Helmert Curve	X								X	
	Sine Curve	X						X			
	Bloss Curve	X									
	Cosine Curve	X									
	Viennese Bend	X									X
Vertical layout	Straight Line		X	X	X	X	X	X	X	X	X
	Circular Arc		X		X	X	X	X	X	X	X
	Parabola						X				
	Clothoid							X			
Cant layout	Constant Straight Line		X	X	X	X	X		X		X
	Linear Transition		X	X	X	X	X		X		
	Non-linear Transition	X									X

Table 4 Conceptual coverage of each Unit Test case

Focused Concept Templates:

- Existing:
    - Spatial Containment
    - Object Nesting
    - Spatial Decomposition
- New or modified:
    - Alignment Decomposition
    - Alignment Geometry
    - Arc Segment
    - Bloss Transition Segment
    - Clothoid Transition Segment
    - Cosine Transition Segment
    - Cubic Transition Segment
    - Helmert Transition Segment
    - Linear Segment
    - Parabolic Transition Segment
    - Sine Transition Segment
    - Viennese Bend Transition Segment

Focused IFC Entities:

- Existing:
    - IfcCompositeCurve
    - IfcCompositeCurveSegment
    - IfcLine
    - IfcCircle
- New or modified:
    - IfcAlignment
    - IfcAlignmentHorizontal

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- IfcAlignmentVertical
- IfcAlignmentCant
- IfcAlignmentSegment
- IfcAlignmentHorizontalSegment
- IfcAlignmentVerticalSegment
- IfcAlignmentCantSegment
- IfcCurveSegment
- IfcGradientCurve
- IfcSegmentedReferenceCurve
- IfcClothoid
- IfcSecondOrderPolynomialSpiral
- IfcThirdOrderPolynomialSpiral
- IfcSeventhOrderPolynomialSpiral
- IfcSine
- IfcCosine

Details of Unit Tests and IFC files produced for this topic are in Appendix B.

4.2 Linear Placement (LP)

4.2.1 Intent

The Unit Tests associated to this Topic are meant to prove the possibility to represent and exchange information about linear placement of products. The Unit Tests shall cover the following alternative representations:

- Placement at point locations
    - Linear placement without considering cant parameters
    - Linear placement that considers cant parameters
    - Both cases above shall be tested with and without lateral and vertical offsets
    - Both cases above shall be tested with and without orientation specification
- Placement at span locations (from/to)
    - With and without lateral and vertical offsets and offsets
- Broken chainage/stationing
    - Testing should include the definition of stationing and broken chainage as a layer of information, using IfcReferent, for alignments and verification that this information can be used to:
        - Transform external chainage values to the internal linear placement representation in IFC (IfcPointByDistanceExpression.DistanceAlong) arriving at the desired location
        - Transform internal IFC representation back to external chainage values, e.g. for presentation for users

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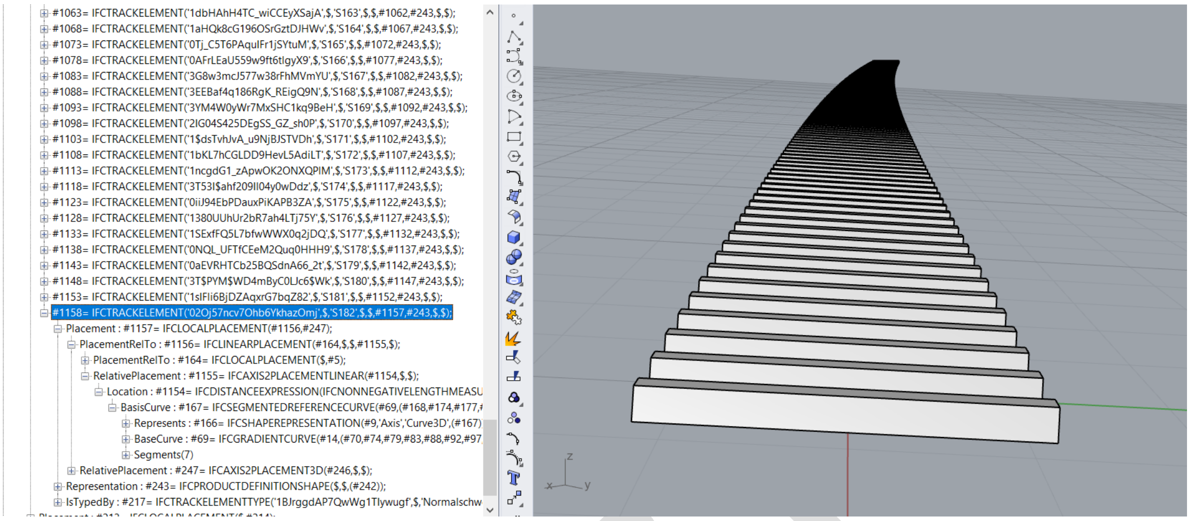

Figure 13 Example of a LP case (UT_LP_3); Sleepers (simplified geometry) linearly placed based on alignment and cant

4.2.2 Associated Unit Tests

There are 8 Unit Test cases documented for testing, covering different aspects of this topic in IFC. The Datasets are mainly provided by stakeholders of the project. To avoid duplication and focus efforts on unique Unit Tests, they were prioritized according to the table below.

ID	Priority	Provider	Unit Test Name
UT_LP_1	1	RFI	Linear placement of catenary posts
UT_LP_2	3	RailComplete	Linear placement 2 (reference alignment)
UT_LP_3	1	SBB	Linear placement of sleeper
UT_LP_4	1	Trafikverket	Broken chainage
UT_LP_5	3	SNCF	Linear placement of Hydraulic Manhole
UT_LP_6	1	SNCF	Linear placement of drainage equipment (Span location)
UT_LP_8	1	CRBIM CRDC	Linear placement of broken chainage
UT_LP_9	3	FTIA	Linear placement of signage

Table 5 Priority overview of Unit Test cases in Linear Placement

4.2.3 Unit Test coverage and IFC scope

The coverage of each case is detailed in Table 6.

	Concepts	**UT_LP_1**	**UT_LP_2**	**UT_LP_3**	**UT_LP_4**	**UT_LP_5**	**UT_LP_6**	**UT_LP_8**	**UT_LP_9**
Alignment layout used for placement	Horizontal							X	
	Horizontal + vertical	X			X				
	Horizontal + vertical + cant			X		X	X		X
Linear placement	DistanceAlong measurement	X		X	X	X	X	X	X
	Lateral offset	X				X	X		X
	Vertical offset	X		X		X	X		X
	Longitudinal offset								
	“Span placement”						X		

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	Explicit orientation (Axis/RefDirection)	X				X			X
	Default orientation	X		X			X	X	
Stationing	Stationing				X			X	X
	Broken chainage				X			X	X

Table 6 Conceptual coverage of each Unit Test case

Focused Concept Templates:

- Existing
    - Object Nesting (for nesting IfcReferent to IfcAlignment)
    - Product Relative Positioning
- New or modified:
    - Product Linear Placement
    - See Alignment with Cant (AWC, see Chapter 4.1)

Focused IFC entities:

- Existing:
    - IfcProduct (any convenient instantiable subtype that shall be placed along an alignment)
- New or modified:
    - IfcRelPositions
    - IfcProduct (any convenient instantiable subtype that shall be placed along an alignment)
    - IfcLinearPlacement
    - IfcAxis2PlacementLinear
    - IfcPointByDistanceExpression
    - IfcReferent
    - See Alignment with Cant (AWC, see Chapter 4.1)

Details of Unit Tests and IFC files produced for this topic are in Appendix B.

4.3 Swept Area Solid (SAS)

4.3.1 Intent

The Unit Tests associated to this topic are meant to prove the possibility to use IfcFixedReferenceSweptAreaSolid and IfcSectionedSolidHorizontal to parametrically model the geometry of elements in railway. The 3D geometric shapes of many elements could be created using this parametric form of geometry, e.g. rails, loading gauge, ballast bed, etc. The Unit Tests shall cover the following alternative representations:

- Sweeping with one profile along a 3D curve
    - Sweeping with fixed reference
    - Sweeping considering cant parameters
- Sweeping with more than profiles along a 3D curve

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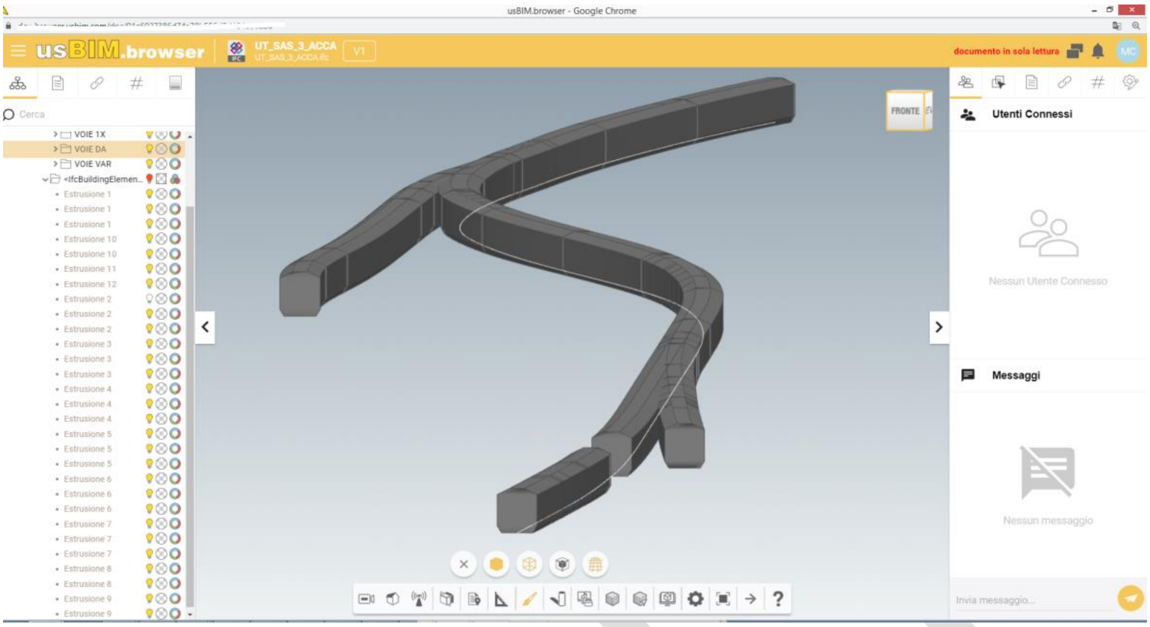

Figure 14 Example of an SAS case (UT_SAS_3); Sectioned Solid as loading gauge

4.3.2 Associated Unit Tests

There are 5 Unit Test cases documented for testing, covering different aspects of this topic in IFC. The Datasets are provided by project stakeholders and software vendors. They were prioritized according to the table below.

ID	Prioritized	Provider	Unit Test Name
UT_SAS_0		Technical Service	Synthetic Cases for Sweeping
UT_SAS_1	1	SBB	Rail Geometry Sweeping
UT_SAS_2	2	ACCA	Track Loading Gauge
UT_SAS_3	2	ACCA	Ballast Bed Geometry
UT_SAS_4	1	SNCF	Bridge

Table 7 Priority overview of Unit Test cases in Swept Area Solid

4.3.3 Unit Test coverage and IFC scope

The coverage of each case is detailed in Table 8.

	Concepts	UT_SAS_0	UT_SAS_1	UT_SAS_2	UT_SAS_3	UT_SAS_4
Alignment layout used for sweeping	Horizontal	X	X	X	X	X
	Horizontal + vertical	X	X	X	X	X
	Horizontal + vertical + cant	X	X	X	X	
One profile based sweeping (IfcFixedReferenceSweptAreaSolid)	Sweeping without cant parameters	X	X	X	X	X
	Sweeping with cant parameters	X		X		
	Arbitrary profile	X	X	X	X	X
	Derived profile	X	X			
	Parametric profile	X				
More than one profiles based	Sectioned solid without cant parameters					X
	Sectioned solid with cant parameters			X	X	

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sweeping (IfcSectionedSolid)						

Table 8 Conceptual coverage of each Unit Test case

Focused Concept Templates:

- Existing
  - Body AdvancedSweptSolid Geometry
  - See Alignment with Cant (AWC, see Chapter 4.1)
- New or modified:
  - See Alignment with Cant (AWC, see Chapter 4.1)

Focused IFC entities:

- Existing:
  - IfcProfileDef (all subtypes of this entity)
- New or modified:
  - IfcFixedReferenceSweptAreaSolid
  - IfcSectionedSolidHorizontal
  - IfcDirectrixDerivedReferenceSweptAreaSolid
  - See Alignment with Cant (AWC, see Chapter 4.1)

Details of Unit Tests and IFC files produced for this topic are in Appendix B.

4.4 Railway Spatial Structure (RSS)

4.4.1 Intent

The Unit Tests associated to this Topic are meant to prove the possibility to allocate space and volume inside a railway project.

The Unit Tests shall cover the following usages:

- Spatial structure of railway projects
  - Use high level spatial decomposition for railway projects
  - Allocate spatial structure for each domain (Track, Signalling, Telecom & Energy) within a railway project
  - Based on usage of IfcRelAggregates and IfcRelContainedInSpatialStructure
- Spatial Zone usage
  - Use of railway-specific Spatial Zone when domain need to share space
  - Use of several Spatial Zone to sort usage of highly shared spaces
  - Based on usage of IfcRelReferencedInSpatialStructure
- Spatial structure of mixed project
  - Use of Railway Spatial structure in conjunction with Infrastructure or Building Spatial structure for mixed project.
  - Use of Railway Spatial Zone with non-Railway spatial structure for foreign space usage on neighbouring infrastructure/buildings.
  - Based on the usage of IfcRelInterferesElements

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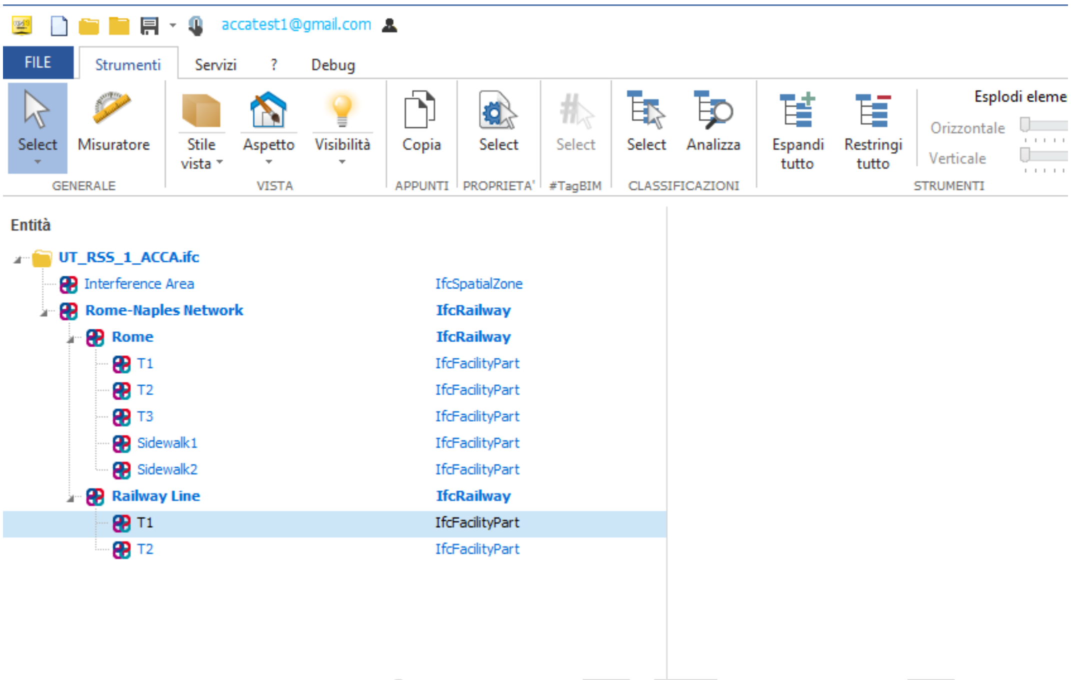

Figure 15 Example of an RSS case (UT_RSS_1); Spatial breakdown of a railway project

4.4.2 Associated Unit Tests

There are 5 Unit Tests documented for testing, covering different aspects of this topic in IFC. The Datasets are provided by project stakeholders. They were prioritized according to the table below.

ID	Prioritized	Dataset Provider	Unit Test Name
UT_SAS_1	1	RFI	Single Domain Spatial Structure
UT_SAS_2	2	MINnD	Early design Railway spatial structure
UT_SAS_3	2	MINnD	Railway spatial structure with geometry
UT_SAS_4	1	FTIA	Multiple Domain Spatial Structure (railway, road, level crossing)

Table 9 Priority overview of Unit Test cases in Railway Spatial Structure

4.4.3 Unit Test coverage and IFC scope

The coverage of each case is detailed in Table 8.

	Concepts	UT_RSS_1	UT_RSS_2	UT_RSS_3	UT_RSS_4
Domain coverage	Railway only	X			
	Cross domain		X	X	X
Relationships	RelAggregates	X	X	X	X
	RelContainedInSpatialStructure				
	RelReferencedInSpatialStructure	X	X	X	
	RelInterferesElements	X		X	X
Facility	Railway	X	X	X	X
	Bridge				
	Road		X	X	X

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	MarineFacility				
	Building				
FacilityPart	RailwayPart	X		X	X
	BridgePart				
	RoadPart				X
	CommonPart				
Spatial Zone	SpatialZone	X		X	

Table 10 Conceptual coverage of each Unit Test case

These tests will focus of following IFC entities:

- Existing:
  - IfcSite
  - IfcSpatialZone
  - IfcFacility
  - IfcBuilding
  - IfcRelAggregates
  - IfcRelContainedInSpatialStructure
- New or modified:
  - IfcBridge
  - IfcRailway
  - IfcRoad
  - IfcFacilityPart
  - IfcRelReferencedInSpatialStructure
  - IfcRelInterferesElements

Details of Unit Tests and IFC files produced for this topic are in Appendix B.

4.5 System Breakdown Structure (SYS)

4.5.1 Intent

The Unit Tests associated to this Topic are meant to prove the possibility to aggregate objects under non geometrical, functional grouping aspects. In particular, as opposed to Spatial Structure, which is typically a hierarchy of elements, System Breaddown Structure tends to be non-hierarchical.

The Unit Tests thus cover the following usages:

- Collect elements in a Group. For this usage IfcGroup, and its subtypes (IfcSystem, IfcAsset) are used to group elements. The relations used is IfcRelAssignsToGroup.
- Collect a Group of elements in another Group. For this usage IfcGroup, and its subtypes (IfcSystem, IfcAsset) are used to create groups of groups and the relationship is still IfcRelAssignsToGroup.
- Reference of a Group to the Spatial structure, e.g., to connect a system to the relevant spatial element that it serves. For this usage the relationship IfcRelReferencedInSpatialStructure is used to refer a Group (and subtypes) to a Spatial Structure Element.
- Associate Psets to groups. For this usage the relationship IfcRelDefinesByProperty is used to associate IfcPropertySet to IfcGroup.

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During the topic discussion, in compliance with the Software Vendors’ request, some requirements were collected from stakeholders:

- An element (subtype of IfcElement) can be part of multiple groups.
  - The relationship to be used is IfcRelAssignsToGroup
- A group (IfcGroup or subtypes) can be part of multiple groups.
  - The relationship to be used is IfcRelAssignsToGroup
- It is possible to have a group that does not belong to another group
- It is possible to have a group that does not belong to a spatial structure element
  - link (logical, functional, topological, etc.) between a group and an element of the spatial structure is possible, but NOT mandatory
  - If this link is required, the relationship to be used is IfcRelReferencedInSpatialStructure
  - The visual rendering of this relationship in a tool's UI is out of scope
- It is required to have a group that belongs to the IfcProject
  - The relationship to be used is IfcRelDeclares

The user should be able to specify the functional breakdown

- The placement for spatial structure element is not required
- Restrictions regrading relationships among groups:
  - Circular reference (e.g., cyclic relationships) is not allowed
    - neither direct (if A groups B, B cannot group A)
    - nor indirect (if A groups B and B groups C, C cannot group A)
  - Level jump is not needed (if A groups B and B groups C, A cannot group C)
  - Same-level grouping is not needed (if A groups B and C, B cannot group C and vice versa)

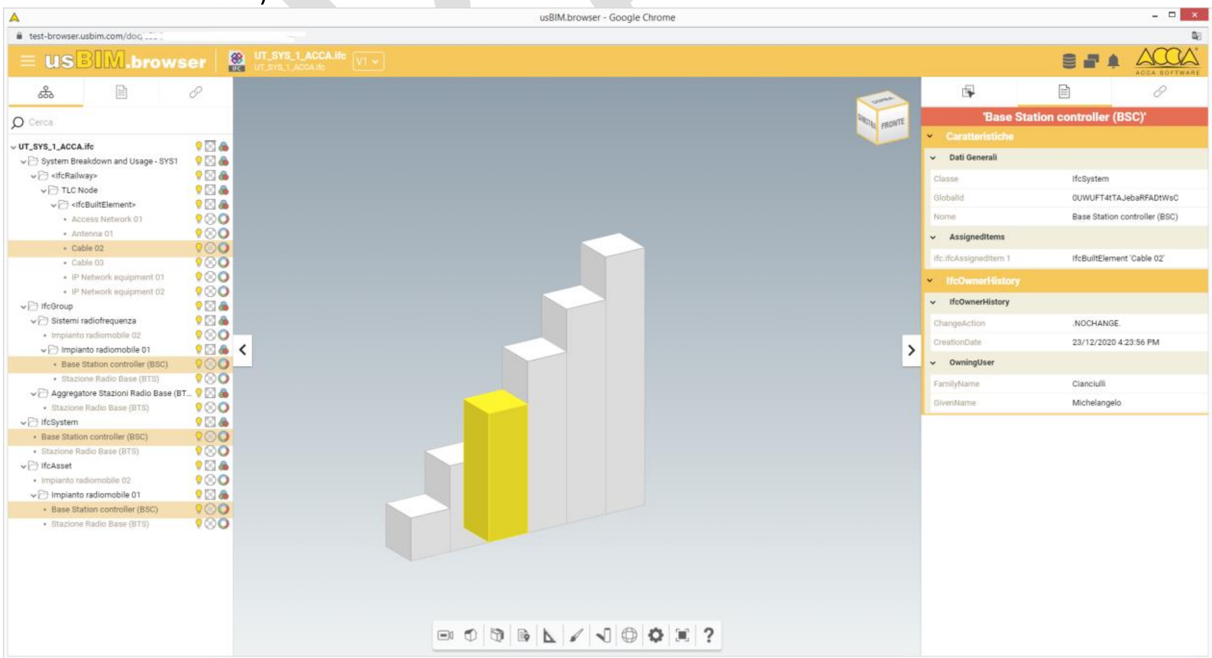

Figure 16 Example of an SYS case (UT_SYS_1)

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4.5.2 Associated Unit Tests

There are 4 Unit Tests documented for testing, covering different aspects of this topic in IFC. The dataset is provided by the stakeholder RFI, as follows:

ID	Priority	Provider	Unit Test title
UT_SYS_1	1	RFI	System breakdown and Group Assignment
UT_SYS_2	1	RFI	Group reference to Spatial Structure
UT_SYS_3	1	RFI	Property Sets for Groups
UT_SYS_4	1	SNCF	System breakdown for Telecom BTS station

Table 11 Priority overview of Unit Test cases in System Breakdown Structure

4.5.3 Unit Test coverage and IFC scope

The coverage of each case is detailed in Table 8.

	Concepts	UT_SYS_1	UT_SYS_2	UT_SYS_3	UT_SYS_4
Domains coverage	Railway only	X	X	X	X
	Cross domain				
Usage	Groups of elements	X	X	X	X
	Groups of groups	X	X	X	
	Group referenced in spatial element		X		X
	Pset associated to groups			X	
Relationships	RelAssignsToGroup	X	X	X	X
	RelContainedInSpatialStructure	X	X	X	X
	RelReferencedInSpatialStructure		X	X	
	RelDefinesByProperty			X	
Included products	Systems	X	X	X	X
	Asset	X	X	X	
	Assemblies				
	Elements	X	X	X	X

Table 12 Conceptual coverage of each Unit Test case

Required existing IFC concept templates:

- Group Assignment
- PropertySets for Objects
- Object Typing

Focused IFC entities:

- Existing:
  - IfcGroup and its subtypes
  - IfcTypeObject
  - IfcPropertySet
  - IfcRelAssignToGroup

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- IfcRelReferencedInSpatialStructure
- IfcRelDefinesByType
- IfcRelDefinesByProperty

- New:
  - IfcBuiltSystem

Details of Unit Tests and IFC files produced for this topic are in Appendix B.

4.6 Port Connectivity (PCC)

4.6.1 Intent

The Unit Tests associated to this Topic are meant to prove the possibility to use IfcPort and relevant IfcRelationship subtypes to realize connections among elements as networks.

The Unit Tests thus cover the following usages:

- Connections between two Distribution Element nesting Distribution Port for power supply, communication or any other types of flows.
- System breakdown of elements linked by ports

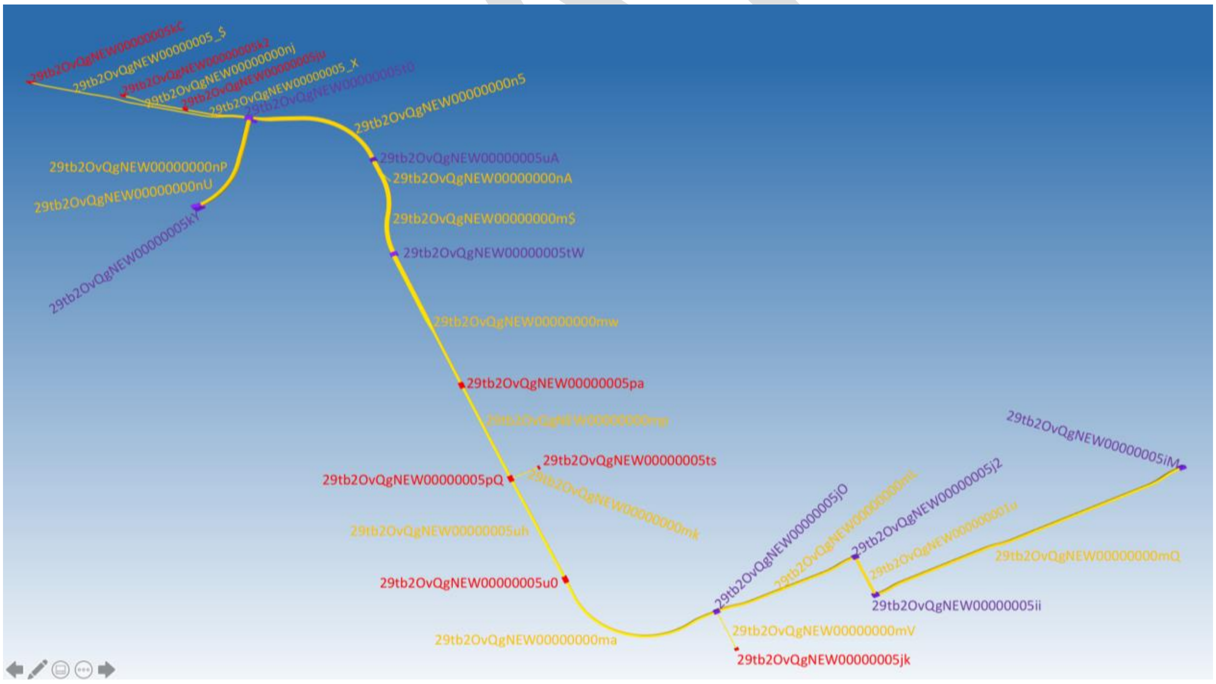

Figure 17 Example of an PCC case (UT_PCC_1); Topology relationship of drainage system

4.6.2 Associated Unit Tests

There are 2 Unit Tests documented for testing, covering two different types of networks. The datasets are provided by the stakeholders MINnD and SNCF, as follows:

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ID	Priority	Provider	Unit Test Name
UT_PCC_1	1	MINnD	Multiduct System topology
UT_PCC_2	2	SNCF	BTS Cluster Wired Network

Table 13 Priority overview of Unit Test cases in Port Connectivity

4.6.3 Unit Test coverage and IFC scope

The coverage of each case is detailed in Table 8.

	Concepts	UT_PCC_1	UT_PCC_2
Domains coverage	Railway only	X	X
	Cross domain		
	Covered railway-domain	Track, Energy	Telecom
Usage	Connections between two Distribution Element	X	X
	System breakdown of elements linked by ports		X
Relationships	RELCONNECTSPORTS	X	X
	RELNESTS	X	X
Entity	Elements	34	X
	Systems	X	X
	Pipe segment	X	
	Cable segment		X
	Distribution port	X	X

Table 14 Priority overview of Unit Test cases in Railway Spatial Structure

Required IFC concept templates

- Existing:
    - Port Connectivity
    - Port Nesting
    - Control Flow

Focused IFC entities

- Existing:
    - IfcRelConnectsPorts
    - IfcRelNests
    - IfcDistributionPort
    - IfcElement
    - IfcDistributionElement and its subtypes
    - IfcDistributionSystem
    - IfcDistributionCircuit
    - IfcRelFlowControlElements
    - IfcFlowSegment subtypes
    - IfcGroup and its subtypes
    - IfcRelAssignToGroup
- New:
    - IfcBuiltElement

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Details of Unit Tests and IFC files produced for this topic are in Appendix B.

4.7 Domain Physical Elements Integrated Test (DPE)

4.7.1 Intent

The Unit Tests associated to this Topic are meant to:

- use tested concepts from UT topics 1-6 (AWC, LP, SAS, RSS, SYS, PCC) to make a more comprehensive case
- check the classifications (entities, predefined types) defined in IFC 4.3 for representing physical elements

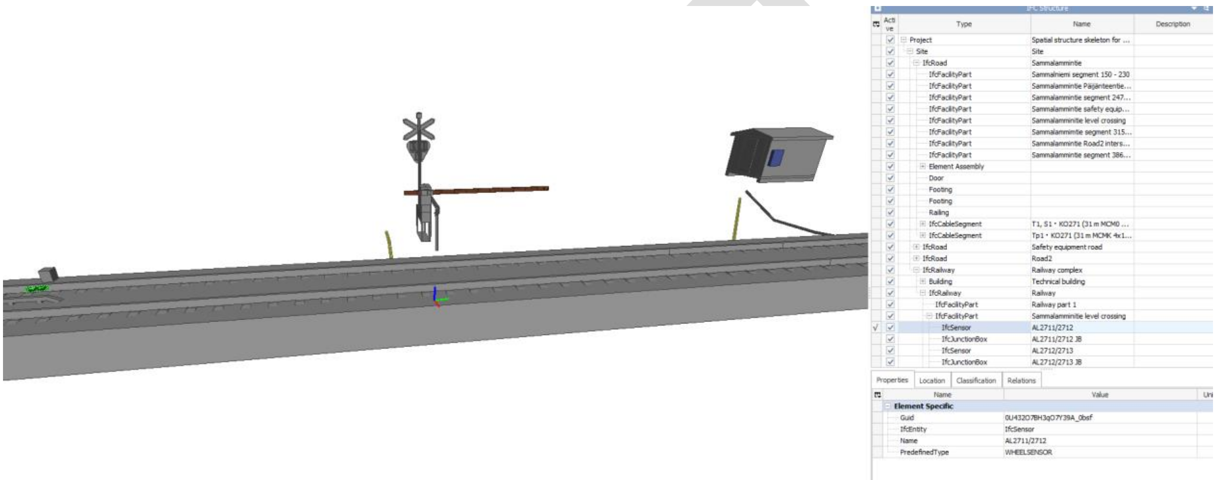

Figure 18 Example of a DPE case (UT_DPE_5); Signalling elements along track alignment

4.7.2 Associated Unit Tests

There are 5 Unit Tests documented for testing, covering two different types of networks. The datasets are provided by the stakeholders, as follows:

ID	Prioritized	Provider	Unit Test Name
UT_DPE_1	2	SBB	Track Turnout Panel
UT_DPE_2	2	RFI	Catenary Post breakdown
UT_DPE_3	2	CRBIM	Signalling elements
UT_DPE_4	2	CRBIM	BTS Telecom elements
UT_DPE_5	2	FTIA	Signalling element and track elements

Table 15 Priority overview of Unit Test cases in Domain Physical Elements

4.7.3 Unit Test coverage and IFC scope

The coverage of each case is detailed in Table 8.

Tier	Business Concepts	IFC Concepts	DPE_1	DPE_2	DPE_3	DPE_4	DPE_5

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Fundamental Concepts	Alignment	Alignment Decomposition; Alignment Geometry; Curve Segment Geometry	X	X	X	X	X
	Cant	Alignment Decomposition; Alignment Geometry; Curve Segment Geometry		X			
	Linear Placement	Product Linear Placement	X	X	X	X	X
	Swept Area Solid	Body Swept Solid Geometry	X				
	Spatial Structure	Spatial Decomposition; Spatial Containment; IfcRelInterferesElements				X	X
	System Breakdown Structure	Group Assignment					X
	Network	Port Connectivity				X	
	Element Assembly Structure	Element Decomposition	X	X		X	
Shared Elements	Pole	IfcMember.POST		X			
	Cable	IfcCableSegment.CABLESEGMENT		X			
	Cable pit/cable trench	IfcDistributionChamberElement.INSPECTIONPIT					
	Footing	IfcFooting.PAD_FOOTING		X		X	
	Cabinet	IfcFurniture.TECHNICALCABINET				X	X
Track	Rail	IfcRail.RAIL	X				
	Check Rail	IfcRail.CHECKRAIL	X				
	Frog	IfcRail.FROG	X				
	Sleeper	IfcTrackElement.SLEEPER	X				
	Blade	IfcRail.BLADE	X				
	Guard Rail	IfcRail.GUARDRAIL					X
	Turnout Panel	IfcElementAssembly.TRACKTURNOUTPANEL	X				
Energy	Dropper	IfcCableCarrierSegment.DROPPER		X			
	Catenary	IfcCableCarrierSegment.CATENARYWIRE		X			
	Cantilever	IfcElementAssembly.SUSPENSIONASSEMBLY		X			
Signal	Signal	IfcSignal			X		X
	Signal Assembly	IfcElementAssembly.SIGNALASSEMBLY					X
	Sign/Marker	IfcSign			X		
	Point machine	IfcActuator.HYDRAULICACTUATOR			X		
	Junction box	IfcJunctionBox			X		X
	Balise	IfcCommunicationsAppliance.TRANSPONDER			X		
	Boom barrier	IfcDoor.BOOMBARRIER					X
	Axle counter	IfcSensor.WHEELSENSOR					X
Telecom	Antenna	IfcCommunicationsAppliance.ANTENNA				X	
	Base transceiver station	IfcSite or IfcSpatialZone or IfcFacility				X	
	Feeder	IfcCableSegment				X	
	Tower	IfcElementAssembly.TOWER				X	

Table 16 Conceptual coverage of each Unit Test case

Required IFC concept templates:

- All concept templates tested in Topic 1-6 (see Chapter 4.1 to 4.6)

Required IFC entities:

- Existing:
  - All existing entities tested in Topic 1-6 (see Chapter 4.1 to 4.6)
  - IfcMember
  - IfcElementAssembly
  - IfcSlab
  - IfcDoor

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- IfcAlarm
    - IfcController
    - IfcSensor
    - IfcFlowInstrument
    - IfcUnitaryControlElement
    - IfcCableSegment
    - IfcCableCarrierSegment
    - IfcCableFitting
    - IfcTank
    - IfcElectricFlowStorageDevice
    - IfcProtectiveDevice
    - IfcSwitchingDevice
    - IfcTransformer
    - IfcHeatExchanger
    - IfcCommunicationsAppliance
    - IfcAudioVisualAppliance
    - IfcElectricAppliance
    - IfcOutlet
    - IfcDiscreteAccessory
    - IfcMechanicalFastener
    - IfcFastener
- New:
    - All new entities tested in Topic 1-6 (see Chapter 4.1 to 4.6)
    - IfcRail
    - IfcTrackElement
    - IfcCourse
    - IfcSignal
    - IfcMobileTelecommunicationsAppliance
    - IfcDistributionBoard
    - IfcElectricFlowTreatmentDevice
    - IfcSign
    - IfcImpactProtectionDevice

Details of Unit Tests and IFC files produced for this topic are in Appendix B.

5 Results

5.1 Overview of test results

As requested by the Stakeholders of the Project, the testing activities have been monitored through some **key performance indicators** (KPIs), to derive the **level of engagement** and the **level of success** of all the parties involved.

The following paragraphs illustrates the major KPIs capturing the results of the testing and validation phase. These are:

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- Investigated Topics;
- Overall Software Vendors' responsiveness;
- Topics coverage from Software Vendors;
- Unit Test coverage from vendors;
- IFC 4.3 reference files produced by the Project;
- IFC 4.3 files (export tests) produced by Software Vendors;
- Issues collected and resolved on GitHub.

IMPORTANT:

- The measurement period is: 4th June 2020 – 30th June 2021
- The sources for the KPIs' measurement are: the GitHub repository of the Project; the MIRO board of the Forum; the meeting minutes and recordings; some direct communications held with software vendors.

5.1.1 Investigated Topics

The testing activities covered **7 Topics**, these are fully described in Chapter 4, and summarise below:

1. Alignment with Cant (**AWC**)
2. Linear Placement (**LP**)
3. Swept Area Solid (**SAS**)
4. Railway Spatial Structure (**RSS**)
5. System Breakdown Structure (**SYS**)
6. Port Connectivity (**PCC**)
7. Domain Physical Elements Integrated Test (**DPE**)

These 7 Topics are further broken down into Unit Test cases, to ease the testing activities. In total, **37 Unit Test cases are created by the Project**, 24 of which (65%) are in priority 1. Below an infographic capturing the relationship between the Topics and the Unit Test cases – with indications on the priority levels and the Stakeholders providing dataset for such tests.

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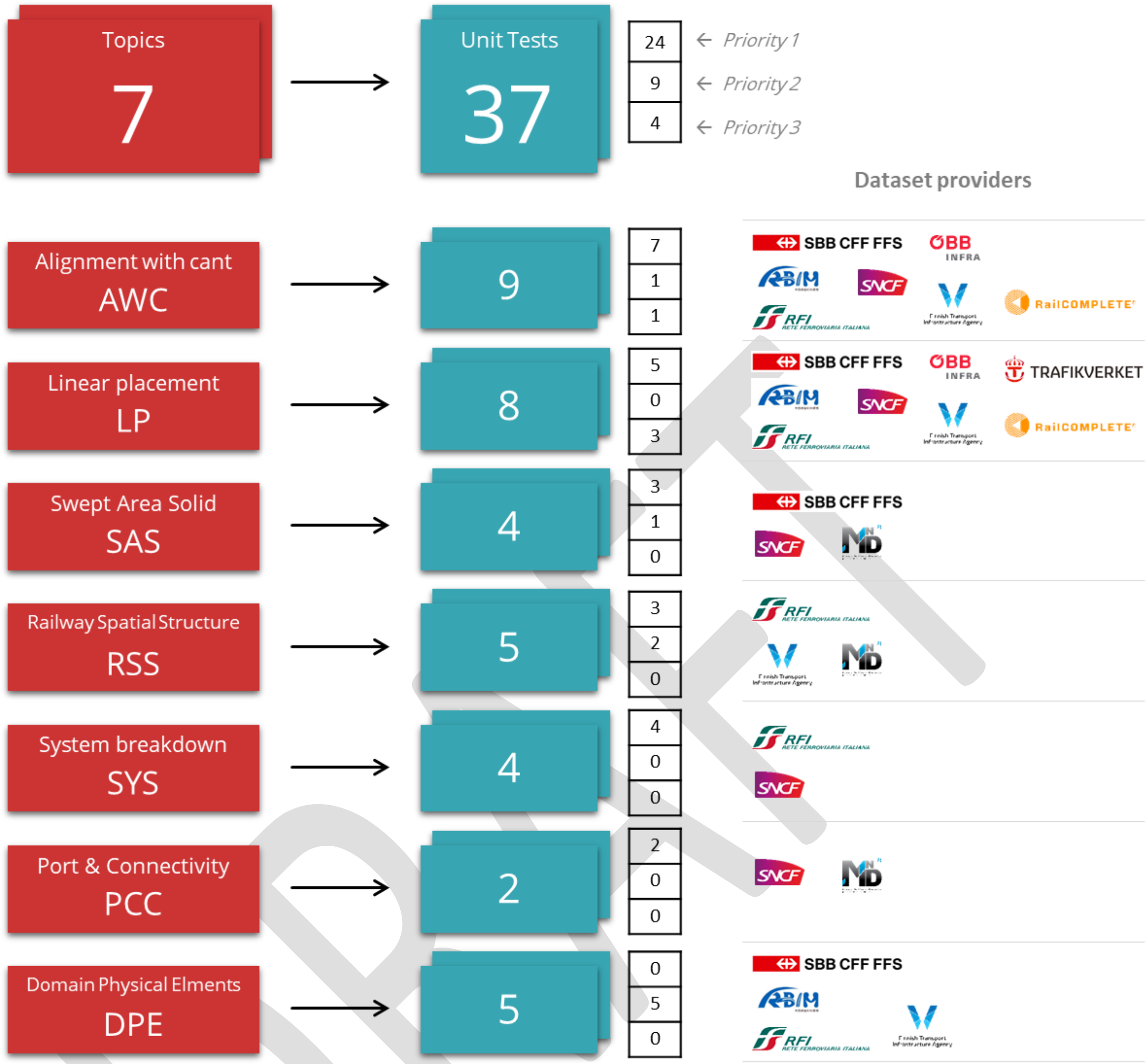

Figure 19 - Infographic of the tested Topics and related Unit Tests

5.1.2 Overall Software Vendors' responsiveness

The goal of the Forum is to engage in a collaborative process with the software vendors that are willing to test the IFC 4.3 standard. This collaboration includes:

- participating in the Forum-related meetings;
- raising questions and doubts;
- proposing changes and improvements to the standard;
- (for writers) exporting IFC files and uploading them on GitHub;
- (for readers) importing the export-tests and sharing feedback.

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Based on the criteria above the following charts are derived, capturing the overall responsiveness (left) and the preferred direction of (import or export) for the active vendors. The majority (**60%**) of the subscribed vendors proved to be active or very active. Within these active vendors, more than half (**59%**) is interested both in reading and writing IFC files; 5 vendors are focusing only on import; 2 only on export.

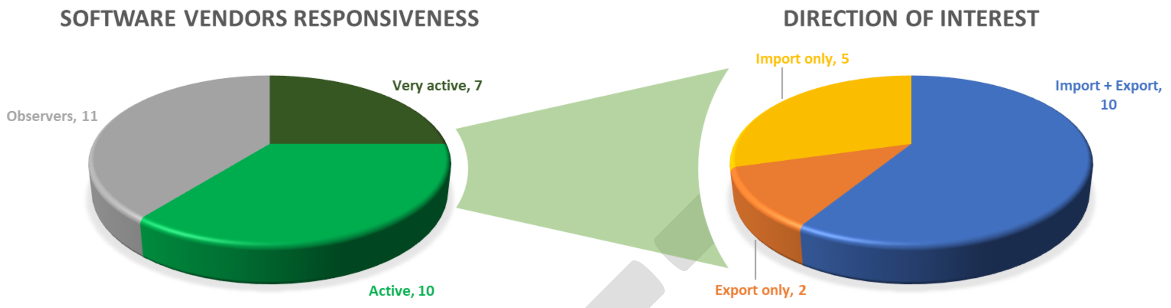

Figure 20 - Overall engagement of software vendors and their direction of preference

NOTE: in the following paragraphs, when metrics are referred to *active vendors* this considers both "Active" and "Very active", so a total of 17 Software Vendors.

5.1.3 Topics coverage from Software Vendors

The Topics of **Alignment** (AWC) and **Linear Placement** (LP) have seen the interest of more than **60%** of the **active vendors**. With all (100%) the active vendors being interested in Alignment. **Less than 4** (<20%) of the active vendors were effectively involved in the Topics of Railway Spatial Structure (RSS) and System breakdown & usage (SYS).

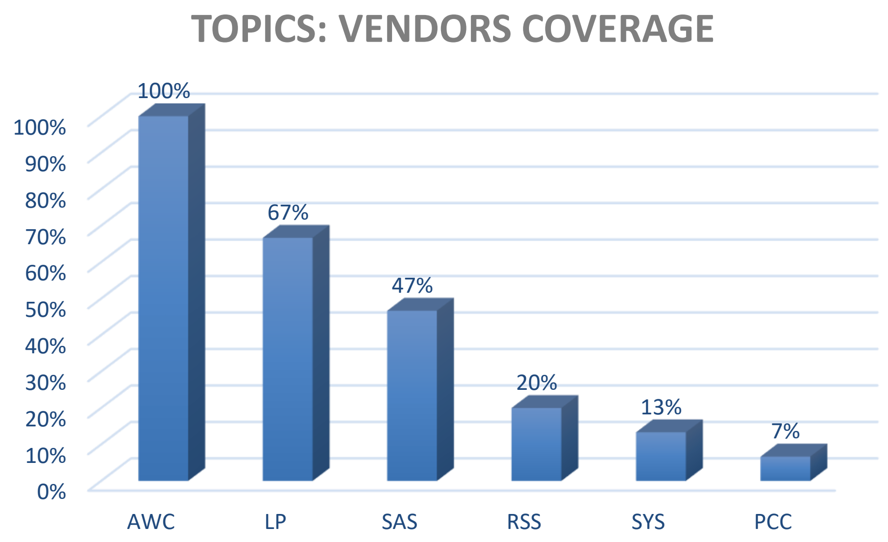

Figure 21 - Topics coverage by software vendors

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This coverage is not fully aligned with the need of Storylines for the same Topics. In fact, the Topics of **Railway Spatial Structure** (RSS) and System breakdown & usage (SYS) are requested respectively by **10** (91%) and **8** (73%) of the **11 Test Leaders** – for their Storylines.

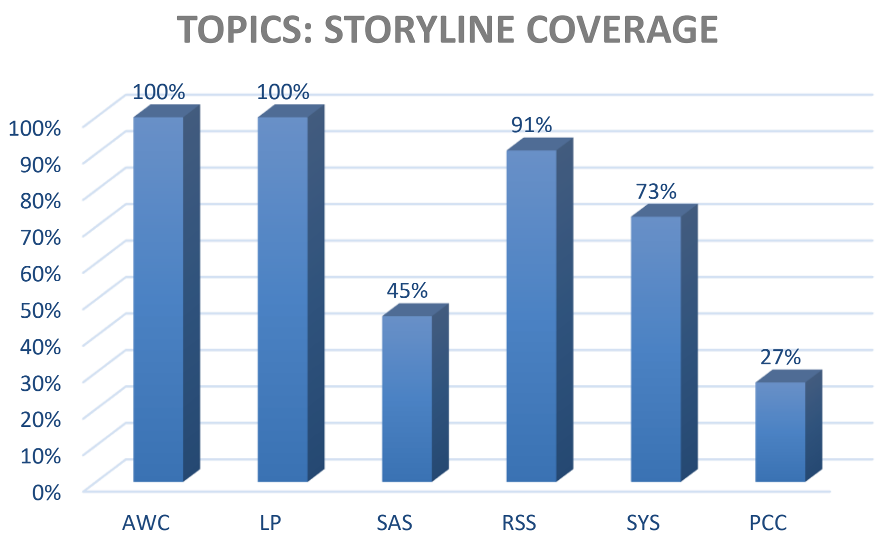
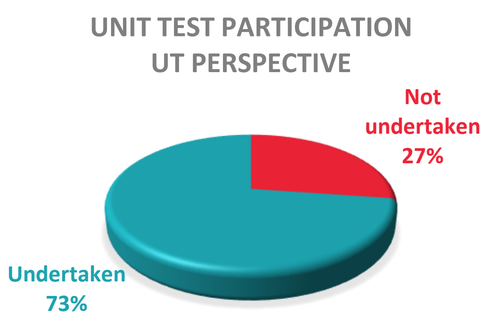
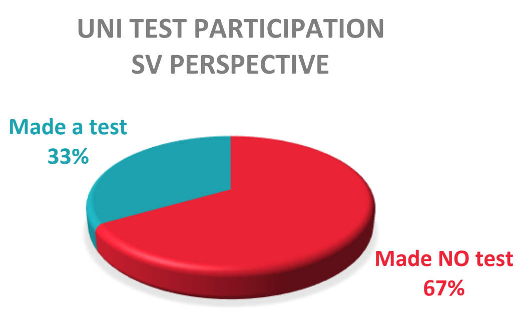


Figure 22 - Topics requested by the Test Leaders for their Storylines

5.1.4 Unit Test coverage from vendors

Of the 24 Unit Tests identified as "Priority 1", almost **three quarter** (73%) have been **undertaken by one or more Software Vendors** (diagram below, on the left). However, concerning the software vendors' contribution to the Unit Tests, only one third (33%) of the active vendors has undertaken at least one Unit Test (diagram below, on the right).





Note that among the **5** vendors (the 33%) which took at least one test, **3 are SDK providers** (they provide software libraries, mainly for geometry, which enable other vendors to implement IFC).

5.1.5 IFC 4.3 reference files produced by the Project

Reference files for IFC 4.3 are essential to prove that the standard can be implemented in software applications. These are provided by the Project for each Unit Test case, and made available to all the

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engaged vendors – for supporting their testing activities. The diagrams below depict the number of reference files produced: i) per priority; ii) per Topic; iii) per Unit Test.

For all the 24 test cases identified as “Priority 1” an reference IFC file is produced by the Project.

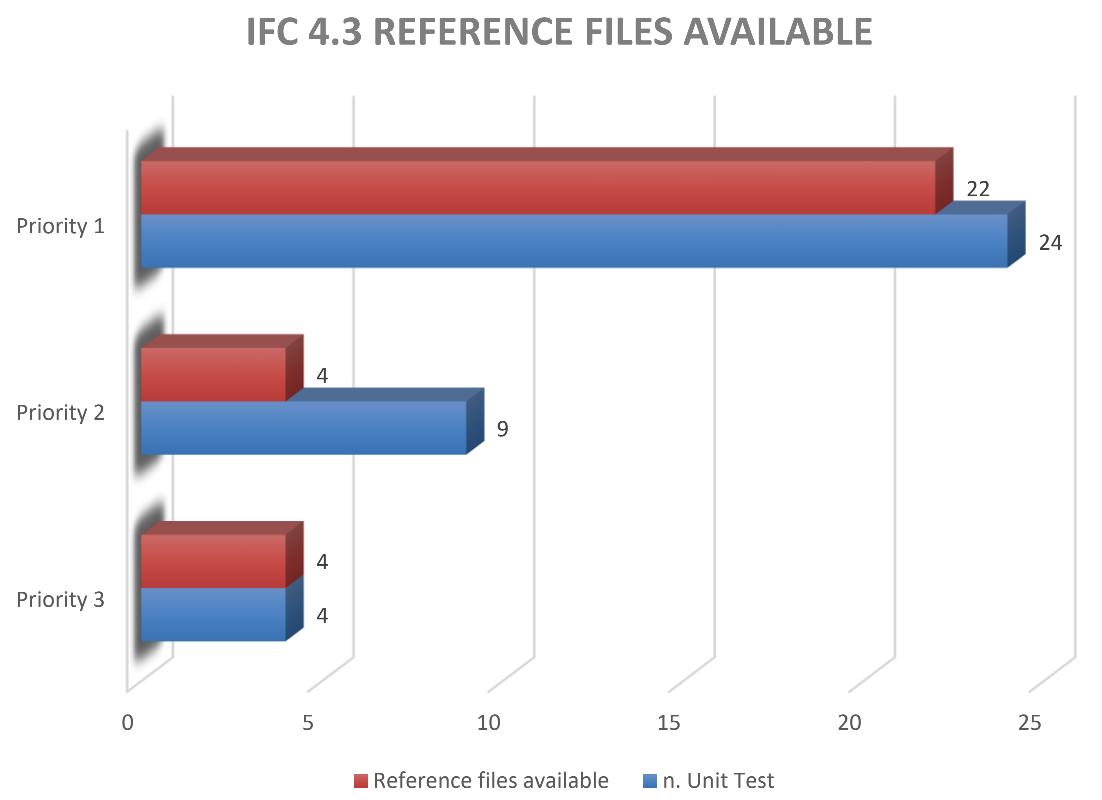

Figure 23 - Total number of IFC 4.3 reference files available, per priority

Among all the IFC 4.3 reference files available, for the Unit Test cases of all priority levels, almost half (48%) is provided for the Topics of Alignment with cant (AWC) and Linear Placement (LP).

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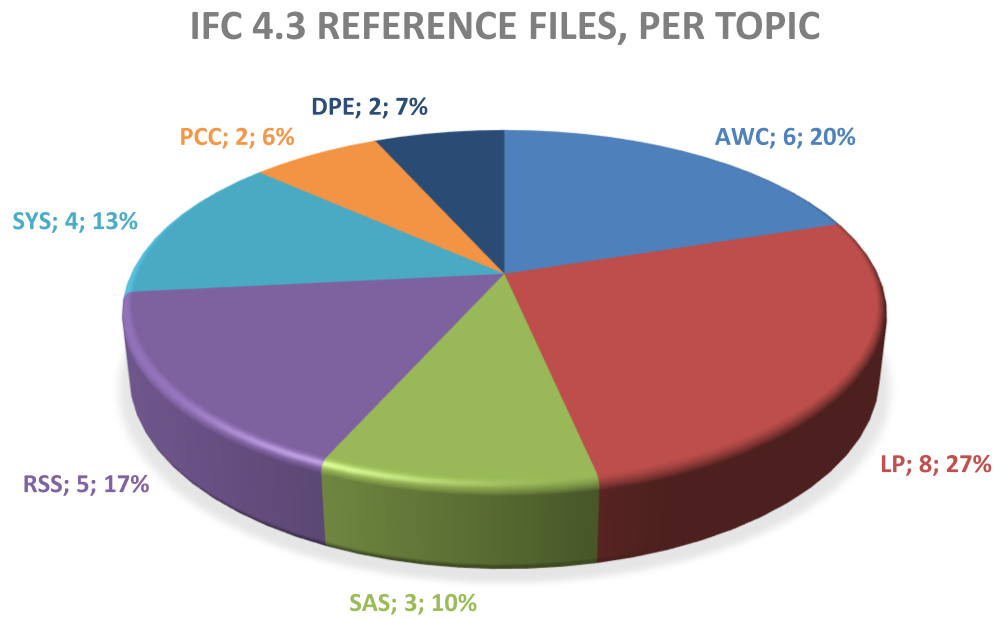

Figure 24 - Number of IFC 4.3 reference files, per Topic

It worth mentioning that 80% (16/20) of the times a reference file has been provided for a Unit Test case, at least on vendor provided an export test for such case. This is depicted in the diagram below.

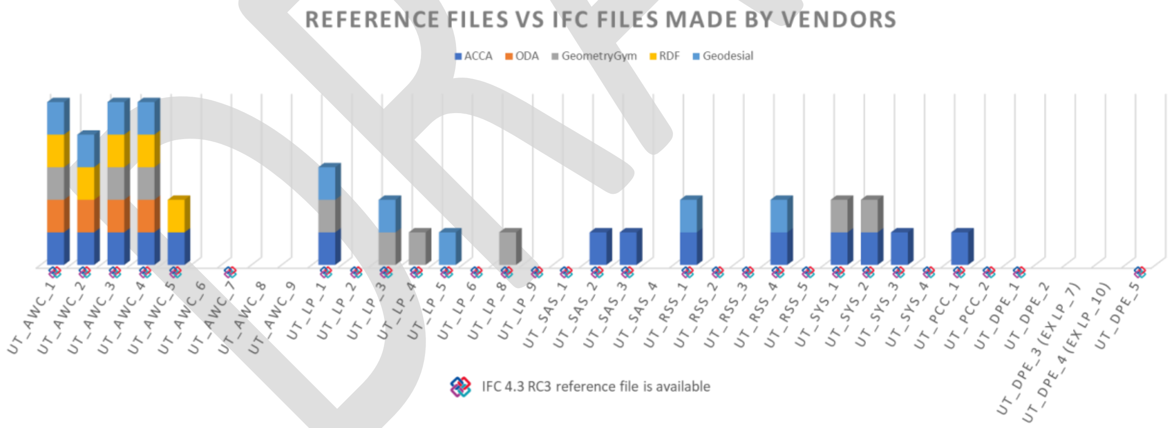

Figure 25 - Number of IFC 4.3 reference files, per Unit Test

COMPACT TEST CASES

In addition to the above mentioned reference files, the Project provided also a set small IFC reference files. These are called compact test cases, and focus on one specific type of alignment segment. Namely: bloss, clothoid, cosine, Helmert curve, sine, Viennese Bend®. For each of six types of curve there are 8 cases, and for each of this 8 cases the Project provided 2 IFC files, one just with the business-

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logi part of alignment and the other including the geometry. In total, **96 compcat IFC reference files**, all validated by the Technical Service. **This brings the total number of available IFC 4.3 reference files to more than 120**.

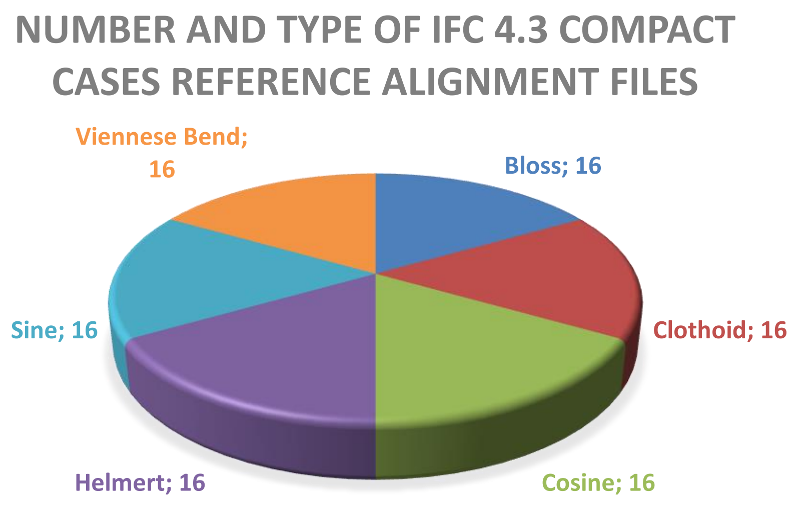

Figure 26 - IFC 4.3 compact cases reference files available

5.1.6 IFC 4.3 files produced by software vendors

Another significant indicator is represented by the number of IFC 4.3 files produced by some of the engaged vendors. This helps proving that the standard can be implemented in the software applications used by the Stakeholders in their daily business. The Project appreciated the commitment of those implementers who kept providing export tests, even if adjustments and changes were happening. In fact, most of the improvements made to the schema are the results of this early iterative collaboration between the Technical Service and the Software Vendors.

Below is a diagram showing the total number of IFC 4.3 export test (41) available, grouped by the producing vendor.

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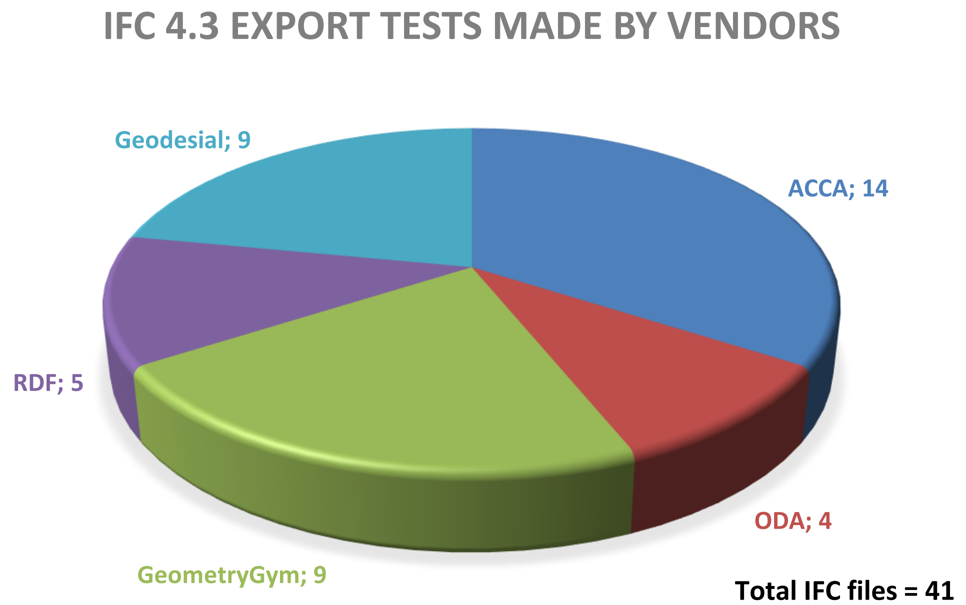

Figure 27 - IFC 4.3 files exported by vendors

Again, note that almost half (**43%**) of the IFC 4.3 export tests are created by **SDK providers** (companies that provide software libraries, mainly for geometry, for other vendors to implement IFC). For this reason, the great effort of **ACCA software** & **Geodesial group** (that together made **57%** of the files) must be recognised even more.

The same data are presented below under a different perspective: the Topics for which the export tests are made.

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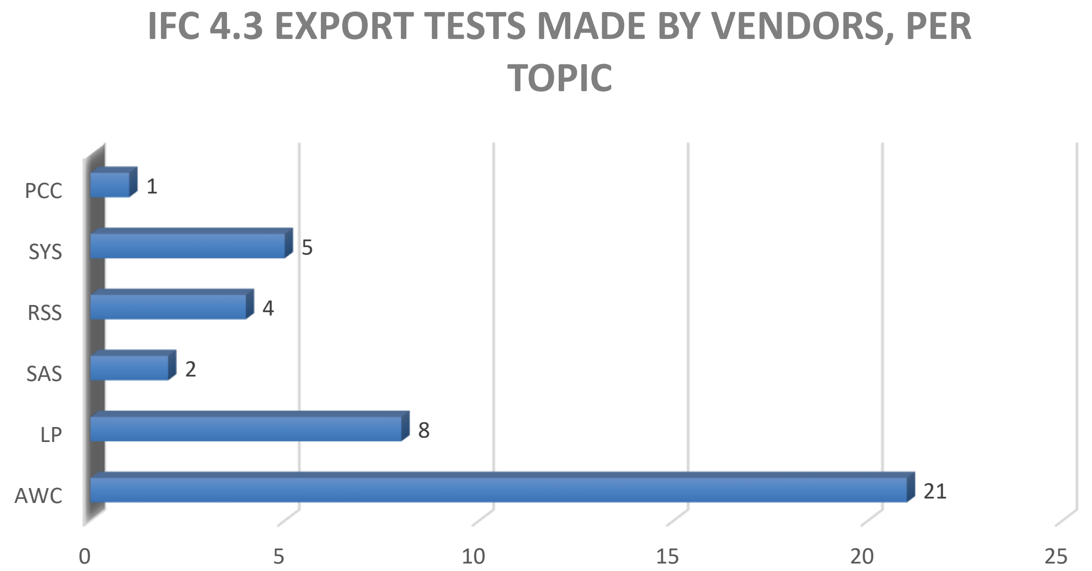


Figure 28 - IFC 4.3 files exported by vendors, per Topic

Finally, another perspective: the number of IFC 4.3 files exported by the vendors for each Unit Test.

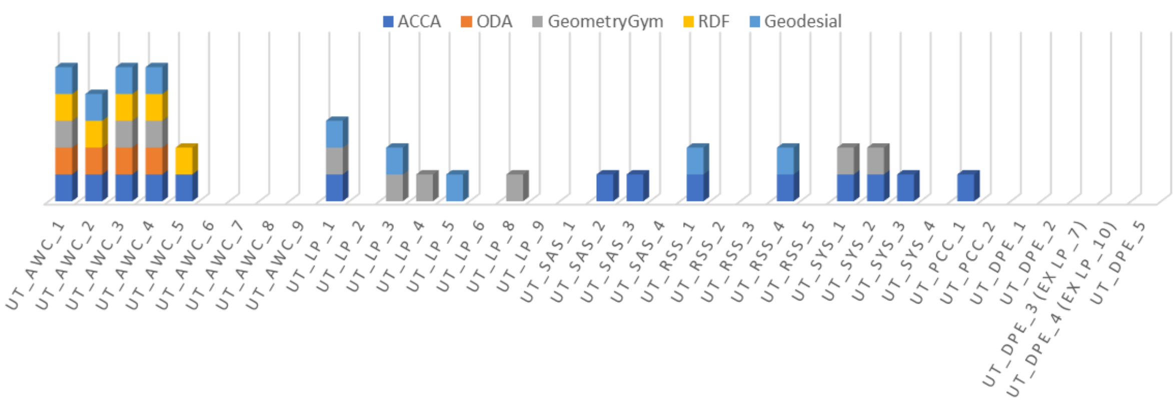


Figure 29 - IFC 4.3 files exported by vendors, per Unit Test

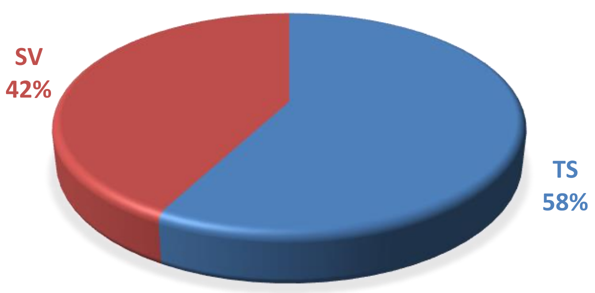
5.1.7 Issues collected and resolved on GitHub

This last KPI is summarising the status of the GitHub issues raised, managed, and resolved during the testing phase. The tracking mechanism offered by this kind of platforms is key to preserve the knowledge around the evolution of the standard, and to understand the rationale behind every change made to the schema, for future reference.

The total number of issues raised in the measurement period is 77, divided as follows:

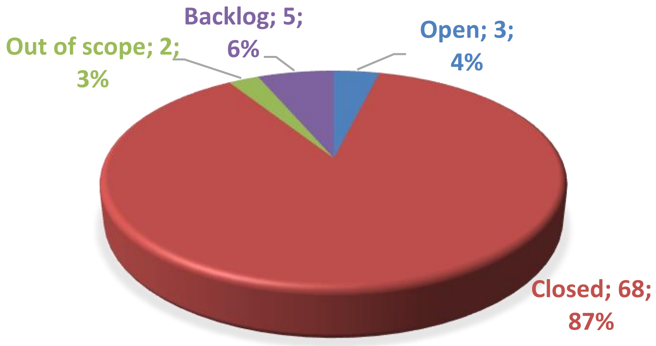
- 56 are questions, bug reports, feature requests, improvements to the documentation
- 21 are Unit Test trackers, used to track but the evolution of a Unit Test case

SOURCE OF THE ISSUES



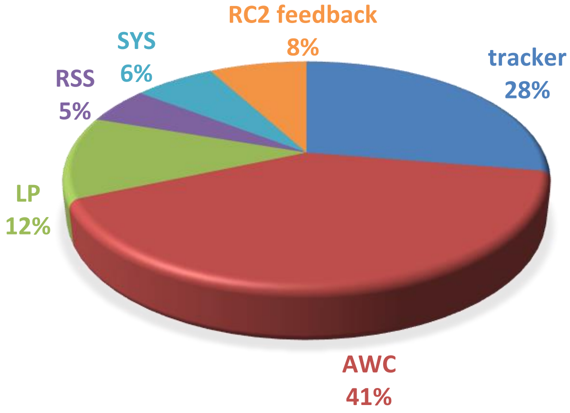
The first diagram divides the issues by the party who created it, namely a software vendor (SV) or an expert from the Technical Service (TS) team.

STATUS OF THE ISSSUES



The second diagram identifies the number of issues which are: Open; Closed; Out of scope; or Backlog, for the Unit Tests' related issues that can potentially be solved in the future.

SCOPE OF THE ISSUES



The third diagram illustrate the scope of the issues. Excluding the Unit Test trackers, the majority (53%) of the issues are raised for the Topics of Alignment with cant (AWC) and Linear Placement (LP).

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5.2 Update of the schema

In this chapter, a few important updates triggered by the work of Unit Tests are described. Some detailed information about updates are described in Annex D and E, and a complete change log is in the IFC 4.3 Specification.

5.2.1 Separate semantics and geometry of alignment

Alignment is an essential concept in railway and other infrastructure domains. IFC 4.3_RC1 inherits the alignment model in IFC 4.1. Following the same approach, on top of alignment horizontal and alignment vertical, the alignment cant was added as an additional layout for alignment, which describes the lateral inclination function of track geometry. In IFC 4.1, the alignment layouts and segments are modelled as geometry resources using terminologies in the alignment domain. This approach, however, causes many issues regarding further extensions and architecture of IFC:

- Since alignment layouts and segments are modelled as geometry concepts, they cannot be extended using the standard property set mechanism in IFC, while in real practice many properties are required to be extended for these concepts.
- The terminologies in the alignment domain lacks a sound mathematical foundation, which easily lead to inconsistent interpretations while mapping to geometry kernels of BIM software packages. Many fundamental functions like e.g. measurement of alignment curve cannot be easily clarified.
- IFC 4.1 and IFC4.3_RC1 have mixed domain terminologies with geometry concepts, which causes confusion in communications: on one side with railway domains experts, and on the other side with software vendors.
- IFC 4.1 and IFC4.3_RC1 have created many dedicated concepts, which are redundant and have overlaps with existing generic concepts in IFC.

Starting from IFC 4.3_RC2, it is proposed to separate domain semantics and geometry of alignment. This update was done by intensive collaboration between IFC Infrastructure Extension Deployment project and IFC Rail project. The major features of this update are listed as follows:

- The alignment layouts and segments are modelled as semantic concepts derived from IfcProduct, so they can be attached with property sets.
- The parameters of alignment segments are defined as non-geometry concepts in the Resource layer of IFC. The terminologies are improved according to alignment domain knowledge.
- A few geometry concepts are extended in IFC using mathematical and geometry terms. They are close to existing concepts in current 3D CAD systems. They can be used as the geometry layer of alignment model. The mathematical aspects of these concepts are clarified.
- The mapping between the "semantic layer" and "geometry layer" are defined. It is documented in Appendix D.
- Existing concepts in IFC are reused as much as possible to enable existing implementations to more easily adapt to the new extension.

The separation of semantics and geometry has always been applied in the architecture of IFC. This update has recaptured this feature and philosophically improved the elegance of model.

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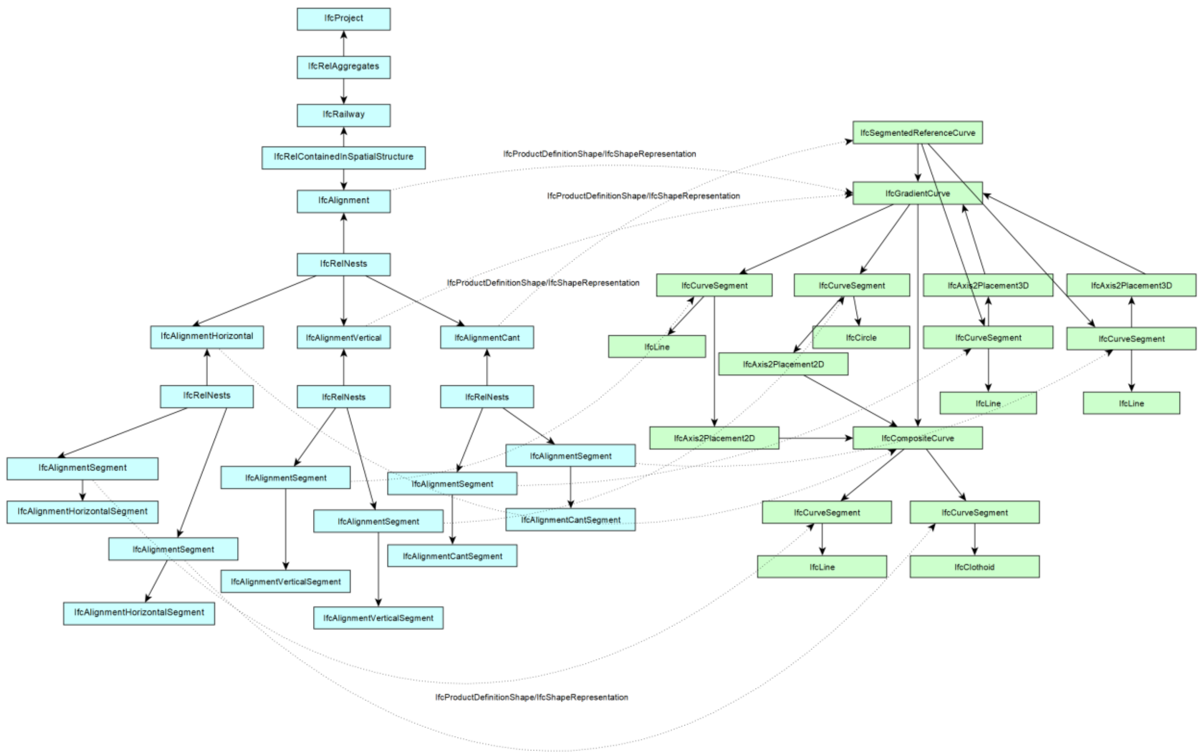

Figure 30 Separation of semantics and geometry for alignment (blue is semantics; green is geometry)

5.2.2 Representation for different transition bends

In railway, a transition bend is a segment of alignment that has transitional curvature. Based on the arc length of the segment, the change of curvature follows a linear or non-linear formula. The curvature formula is closely related to cant formula due to the principle of proportionality between curvature and cant. In IFC Rail phase 2, this topic is revisited to clarify used formulae and enhance geometry concepts in IFC to support this requirement.

In the semantic layer of alignment, the following transition bends are defined:

- Clothoid
- Helmert Curve
- Cubic (an approximation of Clothoid in design documents)
- Bloss Curve
- Sine Curve
- Cosine Curve
- Viennese Bend

All these transition bends have correspondents in cant segments. The formulae are defined based on EN 13803-1.

In the geometry layer, the new branch of curve is defined named IfcSpiral, which is a type of unbounded curve that curvature changes based on arc length. Depends on the equation between curvature of arc length. A set of IFC entities are defined as subtypes of IfcSpiral.

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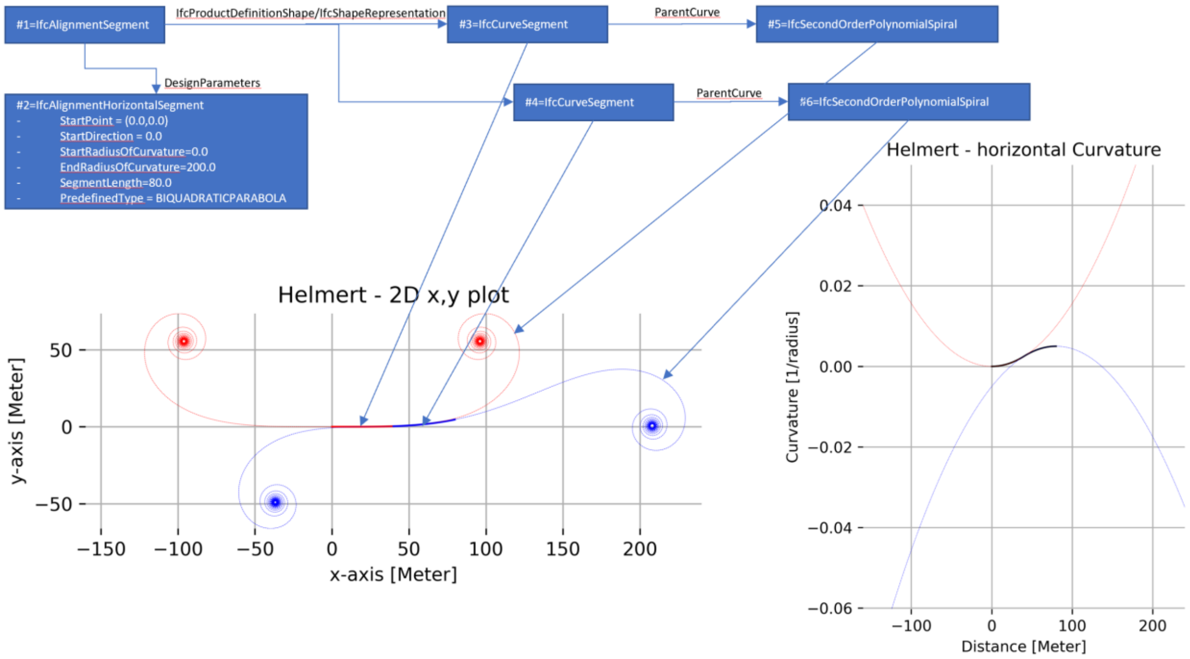

Figure 31 An example of helmert curve transition bend, which is defined by two segments trimmed from two spirals; Transition bends are geometrically represented as segments trimmed from spirals (left plot), which are defined by equations between curvature and arch length (right plot).

- IfcClothoid: the equation between curvature and arc length is a specialized linear function. It can be used as a basis to model Clothoid segment.
- IfcSecondOrderPolynomialSpiral: the equation between curvature and arc length is a second order function. It can be used as a basis to model Helmert Curve segment.
- IfcThirdOrderPolynomialSpiral: the equation between curvature and arc length is a third order function. It can be used as a basis to model Bloss Curve segment.
- IfcSeventhOrderPolynomialSpiral: the equation between curvature and arc length is a seventh order function. It can be used as a basis to model Viennese Bend segment.
- IfcSine: the equation between curvature and arc length contains a sine function. It can be used as a basis to model Sine Curve segment.
- IfcCosine: the equation between curvature and arc length contains a cosine function. It can be used as a basis to model Cosine Curve segment.

The Cubic, as an approximation of Clothoid, could be modelled in geometry by using IfcPolynomialCurve (not an IfcSpiral subtype), which is a curve that defines coordinates through polynomial functions.

Details about transition bends are described in Appendix D and IFC 4.3 Specification.

5.2.3 Updates on Linear Placement

The concept of Linear Placement is defined in IFC since 4.1 version based on ISO 19481-1, which defines a 2D based linear referencing model. This concept is however not adapted to the existing 3D-based Placement mechanism in IFC. Many issues and feedback are collected in the Unit Test phase that

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indicates the Linear Placement is confusing for implementation regarding the way of distance along measurement, direction of offsets and orientation of local coordinate systems.

Starting from IFC 4.3_RC2, this part is updated to generalize the concept Linear Placement. It is defined in a way that is more consistently with how Local Placement is modelled in IFC. A few questions are clarified:

- Distance Along is measured horizontally or based on the 3D curve
- Direction of offset when OffsetLateral, OffsetVertical and OffsetLongitudinal are used
- How to interpret the default coordinate system in Linear Placement, with or without considering cant

Details about Linear Placement are described in Appendix E and IFC 4.3 Specification.

5.2.4 Stationing and Linear Element

Stationing is the fundamental system of measurement used for railway layout and construction. Stations are reference points that are placed along the horizontal measurement of alignment. As a domain semantic concepts, feedback shows that the definition of Station is not explicit and ambiguous with Distance Along, which is considered as geometrical measurement. During the Unit Test phase, the IFC specification has been gradually updated to address this issue. Major achievements are listed as follows:

- The concept Station is defined separately from DistanceAlong. The measurement of station is considered as semantic information defined in property sets, while Distance Along is defined in the schema
- The Station information and related concept "Broken Chainage" are defined as explicit properties in property sets
- Ordering of Stations are done on the semantic layer through IfcRelNests, which is independent with geometry information. This can be used to define "reverse stationing" that Stations are positioned backwards based on alignment axis.

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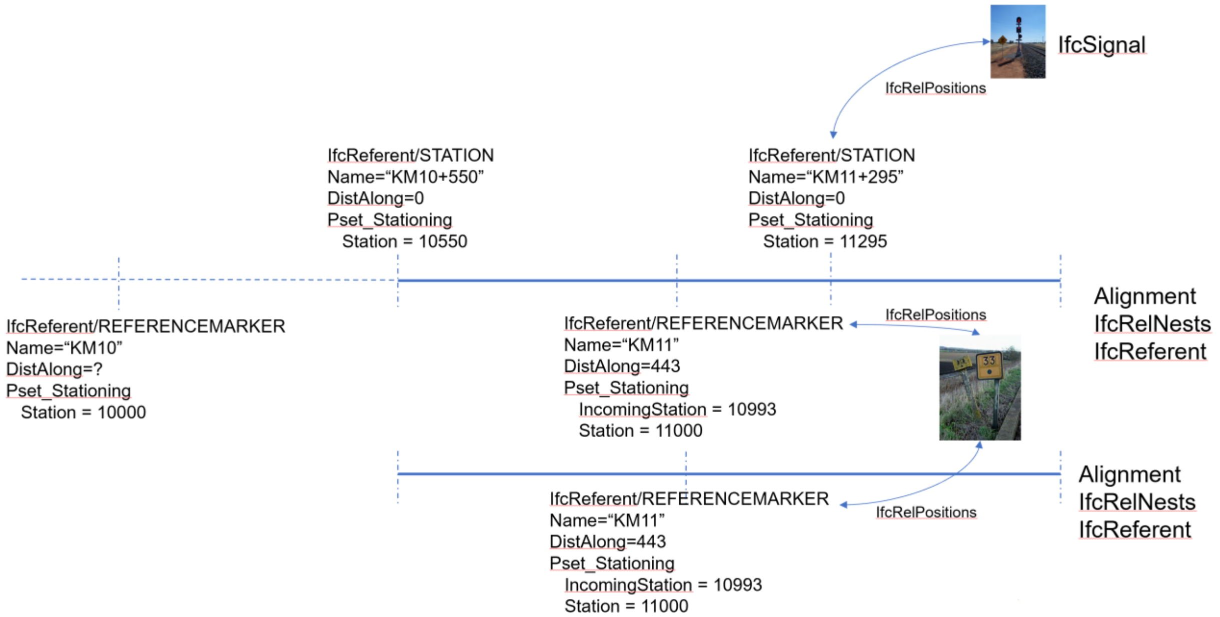

Figure 32 Station and broken chainage are defined in Psets

The Unit Test work has also tackled the concept "span placement", which defines start and end linear referencing information for an element. This concept can be generalized to define a linear concept along the alignment, which can be used to attach properties. Possibilities for using it are e.g. speed properties with start and end position along alignment.

5.2.5 Updates on the Swept Area Solid

As shown in Chapter 4.3, there are many use cases require sweeping a profile along the alignment to parametrically create 3D geometry. There is an existing entity IfcFixedReferenceSweptAreaSolid that can potentially support this requirement. The challenge is that, since IFC Rail project has introduced cant that defines the lateral inclination as the "fourth dimension" of a 3D curve, in some specific cases, the local x axis of the profile shall rotate based on the "fourth dimension".

As briefly introduced in Chapter 5.2.1, the IfcSegmentedReferenceCurve is a geometry concept that can capture the information of horizontal alignment, vertical alignment and cant. It is modelled as a special 3D curve where each point on the curve not only contains x, y, z coordinates but also captures placement that defines a local coordinate system. A new entity is defined as a subtype of IfcFixedReferenceSweptAreaSolid to use the placement information captured in this curve. This new entity will be useful for creating geometry of rail and any other elements that require this type of shapes.

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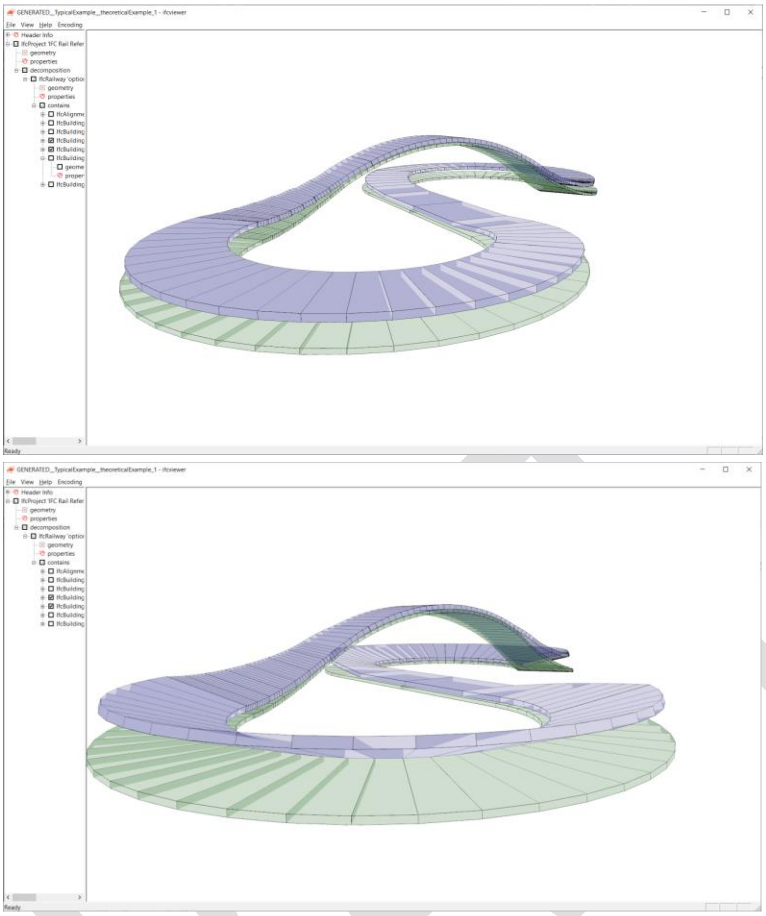

Figure 33 Two scenarios by sweeping a profile through a curve that has "fourth dimension". The upper one is IfcFixedReferenceSweptAreaSolid; the lower one is IfcDirectrixDerivedReferenceSweptAreaSolid

5.2.6 Group structure for asset management

In infrastructure companies, asset management is an important use case. It usually requires to group elements together to management them and attach life-cycle related information. As an existing entity in IFC, IfcGroup can be used for this purpose. This question is to clarify the relationship with the overall breakdown structure in an IFC file:

- What is the relationship between IfcGroup and spatial structure?

In IFC 4.3_RC1, the relationship between IfcSystem and spatial structure was discussed and updated. It was proposed that the relationship between IfcSystem and IfcSpatialElement can be IfcRelReferencedInSpatialStructure. In IFC 4.3_RC2 onwards, to answer the question above, this relationship is generalized, which means IfcRelReferencedInSpatialStructure can be used as the relationship between IfcGroup and IfcSpatialElement. This has led to a minor update in the schema that IfcSpatialReferenceSelect becomes select of IfcProduct and IfcGroup.

This relationship is however not enforced by the standard. For all the IfcGroup instances which do not have this relationship, they can be associated to IfcProject through IfcRelDeclares.

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5.2.7 Interference between Spatial Structure Elements

Spatial Structure in IFC defines a high-level hierarchical project breakdown structure. In Infrastructure project, it is however difficult to break project in a strict hierarchical manner. In IFC 4.3_RC1, IfcRelInterferesElements is updated to define relationships between spatial structure elements, which are in different branches in the Spatial Structure.

In IFC Rail Phase 2, this requirement is updated: not only a semantic “interference” relationship is required between some spatial structure elements, but sometimes also requires to define the inference geometry between them. IfcRelInterferesElements already has an attribute InterferenceGeometry that potentially can be used. However, this attribute introduces issues as it directly defines a geometry element without specifying its context. This entity is updated by adding a new attribute InterferenceSpace, which is an IfcSpatialZone with predefined type “INTERFERENCE” that specially used to define the interference geometry between spatial structure element. When the attribute InterferenceSpace is used, the InterferenceGeometry shall not be used.

5.3 Resolved Issues and Decisions

This chapter lists the resolved issues and agreements regarding the standard. The sources of these issues are:

1 GitHub issues in IFC-Rail-Unit-Test[1]
2 Indepth Technical Discussion Meeting
3 Unit Test Meeting
4 Closed GitHub issues in IFC-Specification that are relevant to Rail

No.[2]	Source	Topic[3]	Description	Conclusion
#1	3	AWC	Missing the approach to flexibly define properties for alignment layouts and segments.	IfcAlignmentSegment is derived from IfcProduct, so are IfcAlignmentHorizontal, IfcAlignmentVertical and IfcAlignmentCant. Two Psets are defined for IfcAlignmentSegment.
#2	1	AWC	Formulae for transition curves in the specification shall be specified.	Formula for all types of segments are redocumented and tested
#3	1	AWC	Rotation point for cant and its impact for resulted geometry.	With attributes in IfcAlignmentCantSegment,

[1] This chapter only lists resolved issues regarding the standard thus many issues posted on GitHub that are related to specific Unit Test cases or datasets are not listed here.
[2] For reporting purpose, this No. is only relevant for this document. It has no relationship with number of issues or pull requests in other places.
[3] A issue usually has impact for more than one Topics. This column only indicates the most relevant one.

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				rotation point has no impact for geometry
#4	3	AWC	Require generic definitions for cant based on different vertical references; vertical alignment is measured from center line, head of lower rail, bottom of lower rail or other possibilities.	Cant is defined by left cant and right cant, which is generic to cover all types of scenarios
#5	3	AWC	Require three layouts as traditional representation for alignment.	The three layouts (IfcAlignmentHorizontal, IfcAlignmentVertical and IfcAlignmentCant) are derived from IfcProduct, which can have its own geometric representation
#6	3	AWC	How to define Viennese bend in alignment?	VIENNESEBEND is defined as a predefined type for IfcAlignmentHorizontalSegment; in geometry part, IfcSevenOrderPolynomialSpiral can be used to defined Viennese bend.
#7	4	AWC	IfcSine and IfcCosine attribute	The schema is updated for all the terms and data types of these two entities
#8	4	AWC	Data type of ConstantTerm for all IfcSpiral subtypes	It is updated to IfcLengthMeasure
#9	4	AWC	Inconsistency of data types for RadiusOfCurvature for IfcAlignmentHorizontalSegment and IfcAlignmentVerticalSegment	The IfcAlignmentVerticalSegment.RadiusOfCurvature is updated to IfcLengthMeasure
#10	2	AWC	IfcAlignment/IfcLinearPositioningElement.Axis is redundant with IfcAlignment/IfcProduct.Representation	IfcLinearPositioningElement.Axis is removed
#11	1	AWC	Requires end point or end position for curves that are defined based on segments as redundant information to e.g. check accuracy	Schema is updated for this
#12	2	AWC	Ambiguity on "Placement" on different levels for alignment segments: IfcAlignmentSegment.ObjectPlacement; IfcCurveSegment.Placement; IfcCircle.Position	The documentation is updated and plenty of sample files are created for this
#13	3	AWC	The convention for defining CW and CCW	CW and CCW are not defined as explicit attributes, but depend on

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				position or negative of radius of curvature
#14	2	AWC	Confusion between IfcAlignmentHorizontal.StartDistAlong and Station	StartDistAlong is removed from the schema. The agreed convention is that all types of “distance along” is considered as geometric measurement that is in the schema, which “station” is a semantic concept that is is Psets.
#15	2	AWC	IfcAlignmentCantSegment: StartDistAlong should be IfcLengthMeasure instead of IfcPositiveLengthMeasure to allow negative offset	It is updated since RC2
#16	2	AWC	The required shape representation identifier and type for IfcGradientCurve and IfcSegmentedReferenceCurve in Alignment	It is agreed to use ‘Axis’
#17	2	AWC	The required segment types and how to represent them using IfcCurveSegment together with IfcCurve as the ParentCurve	
#18	2	AWC	The detailed meaning and illustration update for IfcSegmentedReferenceCurve	The documentation is updated
#19	4	AWC	The confusion caused by the image in the IfcAlignmentVerticalSegment. It mixed Station and StartDistAlong	The image is updated
#20	3	AWC	The confusion caused by attributes in vertical segment in RC1	IfcAlignmentVerticalSegment: Change StartCurvature and EndCurvature to StartGradient and EndGradient
#21	2	AWC	The step-by-step instruction to curve semantic part of alignment to geometry part of alignment	The source code for doing this is shared on IFC-Rail-Unit-Test-Reference-Code repository (see Chapter 3.4.1)
#22	2	AWC	The confusion between Cubic Parabola, Cubic and Cubic Spiral	Only Cubic is in the schema, which is an approximation of Clothoid
#23	2	AWC	The confusion between Helmert and Biquadratic Parabola	Biquadratic Parabola is an approximation of Helmert Curve. Only Helmert Curve is in the schema

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#24	3	AWC	The confusion caused by transition curves in cant segment in RC1	CLOTHOID is made as LINEARTRANSITION in cant segment
#25	3	AWC	What does StartRadius mean in IfcAlignment2DCantSegTransition in RC1	This part is remodelled since RC2 and this attribute is removed.
#26	2	AWC	How to model 'Doucine' in Alignment?	Doucine is not required in geometry in design documents in France, so it is modelled as a property SmoothingLength of IfcAlignmentCantSegment
#27	2	AWC	IfcLinearElement subtypes violate general agreement imposed in IFC 4, that is to remove all direct attributes	This is updated in RC2 and further in RC3 that IfcRelNests is used in the decomposition structure of alignment. Only IfcAlignmentSegment an direct attribute to entities in Resource Layer
#28	1	AWC	Should AdverseCant in LandXML be modelled in IFC as properties?	It is redundant with horizontal and cant information and can be derived, so it is not in the standard.
#29	1	AWC	StartHeight in vertical alignment shall be defined as StartElevation, which is measured from mean sea level?	StartHeight defines the height in the context of alignment, so it is not measured from mean sea level. StartElevation is defined as a property of IfcAlignmentVerticalSegment, so is EndElevation.
#30	1	AWC	How to interpret the redundant information in IfcAlignmentVerticalSegment	HorizontalLength as a mandatory attribute should drive the interpretation for geometry; RadiusOfCurvature is an OPTIONAL attribute.
#31	1	AWC	An error in IFC4.3_RC1 regading IfcLinearAxisWithInclination that it is not possible to be linked with IfcLinearPositioningElement through Axis	Not relevant anymore since RC2, as this part is remodelled and IfcLinearAxisWithInclination is removed.

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#32	2	LP	Parameterization of new curve types	The parameterization of a IfcGradient, IfcSegmentedReferenceCurve and IfcOffsetCurvebyDistances are all based on parameterization of the BasisCurve. The parameterization of IfcSpiral subtypes is documented in the specification.
#33	3	LP	How to model broken chainage in IFC?	A Pset Pset_Stationing is defined to capture the explicit information for broken chainage.
#34	2 and 3	LP	Require generic definition for linear placement and clarify the meaning of each attributes by improving documentation.	The schema and documentation has been updated since RC2
#35	2	LP	The offset direction of IfcPointByDistanceExpression, especially when it is used on IfcSegmentedReferenceCurve	The documentation and sample files clarify this question (specifically the file for UT_LP_3)
#36	2	LP	The default direction of IfcAxis2PlacementLinear.Axis and IfcAxis2PlacementLinear.RefDirection, especially when it is used on IfcSegmentedReferenceCurve	The documentation and sample files clarify this question (specifically the file for UT_LP_3)
#37	3	LP	How to associate an IfcReferent and the IfcAlignment that it is positioned on	IfcRelNests shall be used. The ordering of the list shall follow the order of Station
#38	2	LP	How to trace from the element back to the alignment it is placed based on	IfcRelPositions can be used between an IfcElement or an IfcSpatialElement and the IfcAlignment that it is positioned on
#39	1	LP	How can the the Linear Referencing Methods defined?	A new Pset Pset_LinearReferencingMethod is defined
#40	1	LP	How to define measurement along horizontal for DistanceAlong in linear placement	It is agreed that regarding DistanceAlong for IfcGradientCurve and IfcSegmentedReferenceCurve, the measurement is done based on its

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				BasisCurve, which will be an IfcCompositveCurve in most cases. In this case, DistanceAlong can be defined as horizontal measurement.
#41	1	LP	How to define "Span Placement" in IFC since the update in RC2?	An IfcProduct is allowed to associate more than one IfcRelPositions. For "span placement", one IfcProduct can be related to two IfcRelPostions, each of which is related to an IfcReferent. The schema is updated for this.
#42	2	LP	How to define "Linear Properties" like speed in IFC. They should be attached to a concept that has start station and end station	IfcLinearElement is defined as non-abstract for this purpose.
#43	3	SAS	What is meaning of FixedReference of IfcFixedReferenceSweptAreaSolid	The FixedReference defines the local-x axis, which is the projection onto the normal plane to the directrix at the point. Documentation is updated and sample files are created
#44	2	SAS	How to interpret FixedReference for a sweeping considering cant	A new entity IfcDirectrixDerivedReferenceSweptAreaSolid is extended for this purpose
#45	3	RSS	How to use IfcRelInterferenceElements.RelatingElement and IfcRelInterferenceElements.RelatedElement and the direction of interference implied in this entity	The documentation is updated
#46	3	RSS	IfcRelInterferencesElements.InterferenceType should have predefined types as enumeration or at least clearly documented in the entity	The documentation is updated
#47	1	SYS	IfcGroup cannot relate to IfcRelReferencedInSpatialStructure	The schema is updated to support this
#48	3	SYS	How to link Group to the project breakdown structure	Either through IfcRelReferencedInSpatial Structure to an IfcSpatialStructureElemen

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				t or through IfcRelDeclares to IfcProject
#49	3	SYS	How to define “Group of groups”	A group (IfcGroup or subtypes) can be part of multiple groups. The relationship to be used is IfcRelAssignsToGroup. Some restrictions applies (follows) a. Circular reference (e.g., cyclic relationships) is not allowed, neither direct nor indirect; b. Only direct inclusions allowed (if A includes B and B includes C, A cannot includes C) c. Same-level grouping is not allowed. Meaning, If two or more Group are part of the same Group, they cannot include each others
#50	3	DPE	Base Transceiver Station (BTS) as a “container” for all the elements inside it cannot be modelled as an IfcElement subtype	BTS has two meanings in railway, either as site based “spatial container” for elements, as BTS cabinet. In the first case, it shall be defined as a spatial structure element. This can be generalized for substation and other site-based facilities along railway.
#51	4	DPE	Requires more PDTs for the Signalling domain	RECORDINGEQUIPMENT and LINESIDEELECTRONICDEVICE are added as new PDTs for IfcCommunicationsAppliance
#52	4	DPE	Requires more PDTs for the Telecom domain	The schema is updated. New PDTs are added for IfcMobileTelecommunicationsAppliance, IfcCommunicationsAppliance, IfcAudioVisualAppliance, IfcDistributionBoard,

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				IfcUnitaryControlElement and IfcDistributionSystem
#53	4	OTHERS	Entities and types in IfcRail subschema need to be reorganized	The IfcRail subschema is updated to IfcRailDomain. Entities are reorganized
#54	1	OTHERS	IfcLengthMeasure documentation should remove "Usually measured in millimeters"?	The documentation is updated
#55	4	OTHERS	Empty Psets from Rail are in the specification	Empty Psets are removed

Table 17 The list of resolved issues

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6 Conclusion & Future work

The purpose of Unit Test is to test the standard through small cases in order to 1) check the validity of the standard; 2) improve the standard based on collected issues; 3) facility the implementation and deployment. This report together with IFC 4.3 specification and all the other documents from IFC Rail project and IFC Infrastructure Extension Deployment project are an important milestones by both projects. They ensure a solid IFC 4.3 schema to be further deployed in Storylines in IFC Rail and follow-up projects in the infrastructure domains. From IFC Rail perspective, the future work can be summarized as follows:

- The IFC 4.3 Specification will be further deployed in Storylines, which will require more comprehensive exchanges in the context of business processes. The project will continue organize software vendors together with Stakeholders and Technical Service to collaborate.
- The project will cooperate with InfraRoom and bSI to define MVDs for certifications. The priority of MVDs is an Alignment-based Reference View. Two work threads will be in parallel: 1) a “base MVD” which defines a common grounding including geometry and other shared information between infrastructure domains; 2) specifying exchange requirements for Railway industry, which will mostly be formalized as property sets based on the outcome of IFC Rail Phase 1.
- Further harmonization of property sets and bSDD input. Property sets from Rail will be further defined and harmonized into further releases of IFC 4.3. At the end, it is also aimed to import the final property sets from Rail into bSDD.

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Appendix

A. List of Software Vendors

See Appendix A

B. IFC files and description

See Appendix B. The GitHub for IFC files from Rail is on: https://github.com/IFCRail/IFC-Rail-Sample-Files

C. Coverage table

See Appendix C.

D. Alignment Rework Report

See Appendix D.

E. Linear Placement Rework Report

See Appendix E.

F. Property Set Harmonization Report

See Appendix F.

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