Conférence Européenne des Directeurs des Routes

Conference of European Directors of Roads

AMSfree

CEDR TRANSNATIONAL ROAD RESEARCH PROGRAMME

WP 6 Data Exchange to Legacy Systems

D6.1 Guideline IFC Property Mapping
D6.2 IFC Property Mapping Examples
D6.3 IFC Mapping Software Architecture
D6.4 Guideline Exchange of Linked Data using Information Containers

Document Name: AMSfree_Guidelines_1
Version: 1.0
Date: 2022-02-28

Authors: Stöckner, M.; Zwernemann, P. (UAS Karlsruhe)
Hajdin, R.; Schiffmann, F.; Blumenfeld, T. (IMC Zürich)
König, M.; Liu Liu (RUB Bochum)
Gavin, K.; (INGeo, Deflt)

January 2022

Table of contents

Table of figures

Abbreviations

AMS	Asset Management System
BIM	Building Information Modelling
BMS	Bridge Management System
IAMS	Infrastructure Asset Management System
IFC	Industry Foundation Class
NRA	National Road Authorities
MR&R	Maintenance, Repair, and Rehabilitation
OWL	Web Ontology Language
RDF	Resource Description Framework
S&A	Survey and Assessment (especially for roads)
UML	Unified Modelling Language
URI	Uniform Resource Identifier

1 Introduction

1.1 Aim of the Guideline

The aim of this document is to provide users of Building Information Modelling (BIM) from National Road Authorities (NRA) with a guideline to implement approaches developed in the AMSfree project. This document includes instructions for exchanging linked data between Infrastructure asset management systems (IAMS) and BIM using information containers. It includes the development of a transformation concept for data exchange between different legacy systems and a procedure for the systematic integration of existing asset data in different NRA by means of ontologies.

This guideline provides a basis for data exchange between Infrastructure Asset Management System, IAMS databases and BIM models. This includes a description of the proposed approach, use cases, the software and data/file formats as well as an two examples of the application of the developed concepts; the first for a road section and the second for a bridge. It gives a detailed explanation on how to proceed as a user in updating the AMS database to mirror physical reality. The appendix includes the guideline for IFC property mapping (D6.1), some examples on property mapping (D6.2) and the IFC mapping software architecture (D6.3).

1.2 Infrastructure Asset Management

Asset Management is a long-term, strategic process of managing road assets effectively during their lifespan [PIARC, 2017]. Therefore, IAMS is an aid to infrastructure asset managers in their decision-making. Such systems often cover a wide range of functionalities ranging from inventorying physical infrastructure to making predictions regarding an asset's performance and maintenance planning. In the effort towards standardising the processes of infrastructure asset management, the International Organization for Standardization, ISO standard 55000 ((ISO 2014) was published in 2014. It highlights the importance of leadership and a clear organisational strategy leading to improved processes and the effectiveness of the management.

An asset management system for the entire life span consists of different levels. The strategic asset management plan (SAMP) defines the overall goals of a NRA in terms of asset management. The asset management plan (AMP) defines all activities, resources, and prioritization of maintenance, repair, and rehabilitation (MR&R) interventions. The MR&R defined in the AMP are implemented for the individual assets and monitored for performance evaluation and improvement measures. CEDR has published a report outlining an approach to the implementation of the ISO norm for road authorities, (CEDR, 2017).

The success of the AMS process depends on the availability of high-quality data. The data required includes; inventory data, condition data and data on executed maintenance intervention and their outcome. Common IAMS for different NRA's are described in the AMSfree Reports D 2.1 "Comparative analysis of IAMS in and common BIMs in Europe". Data demands for condition survey and assessments are outlined in Report D 3.1 "Current assessment techniques" and Report D 3.2 "Information Delivery Manual (IDM) for condition Assessment". Report D 4.1 "Definition of an Asset Management reference process" contains the basics and data inputs for a generic AMS Process.

1.3 Building Information Modelling and IAMS

BIM has already been successfully tested in pilot projects focused on planning and construction of infrastructure assets at European NRAs. The method relies on an open and vendor-free data exchange format to allow communication between different software packages utilised during the planning and construction process. In order to accomplish the full interoperability between various commercial BIM software, buildingSMART International (bSI), developed Industry Foundation Classes (IFC), an open standard specifying vendor-neutral data format. IFC files comply with the IFC schema, which can be written in the EXPRESS data modelling language, defined in ISO 16739:2013.

For roads and bridges, various extensions to IFC are currently being developed to enable an efficient data exchange. The concepts and principles of information models using building information modelling are defined in ISO Standard (ISO 19650-1:2018). ISO 19650 comprises the entire life span of infrastructure, including strategic planning, object-related planning, construction, operation, maintenance, rehabilitation (MR&R) and demolition. However, BIM is still rarely used by NRAs in operation and planning of MR&R interventions on infrastructure assets, which is regrettable as it promises significant benefits, especially, but not exclusively, for NRAs.

If using BIM during the operational period of an asset, it is necessary to create a geometric BIM model that is enriched with data from the IAMS-Database. Currently, data is imported into the IFC model manually. One of the aims of the project is to enable data exchange with the help of information containers. Data can be thus easily be loaded into the model. These IAMS databases are based on data models that vary widely between road authorities. In particular, the level of granularity by which assets are modelled in the infrastructure management databases differs significantly. In addition, most lack adequate visualisation.

In the above mentioned AMSfree reports and especially in the reports D4.2 and D4.3 "Information Container for Road Maintenance Planning and Bridge Condition Assessment" and the reports D5.1 "IAMS-oriented Information Delivery Manual", D5.2 "IAMS-oriented Application and Extension of the IFC Standard" and D5.3 "Linking Guide of European Road OTL and National Classifications" basic information on data linking between a Building Information Model and IAMS is established. To fully exploit the Information Container for linked Document Delivery (ICDD), information linking between BIM and other information in the ICDD on the one hand and between ICDD and IAMS on the other hand needs to be enabled. Whereas the former is enabled using the recommended ontologies in ISO 21597 for the establishment of the ICDD and using the domain ontologies for the semantic data collection, the latter needs to be established by means of an Information Delivery Manual (IDM). This describes the integration of RDF-based data from the information container (i.e., data structure compliant to the ICDD - ISO 21597) into the existing IAMS (relational database), and procedures for extracting data from IAMS to ICDD. These guidelines explain the use of ICDD based on a prototype and examples to allow for ease of implementation by NRAs.

1.4 Overall Context and Structure of the Guideline

This guideline consists of five chapters including an appendix which contains a brief description of the basics for BIM modelling for infrastructure asset management.

When starting with BIM modelling it is necessary to first analyse all relevant data that should be included into the modelling process. Therefore, for each period in time it needs to be decided which data is exchanged or updated during the life span of an asset. It is recommended to sketch up these points in time including all relevant information using flow charts, described in chapter 2.

Chapter 3 describes the basics of the BIM workflow and related software. In order to create, edit and exchange geometric models as well as to enrich them with data sets, specific software tools are used. Chapter 3.1 gives an overview to the different BIM models starting from the planning phase through the construction phase and finally leading to the operation phase. In the context of BIM, ontologies are used to provide data schemas. Ontologies are described by a document or a file that formally defines the relations among terms. This is needed to define how to process and interpret data. By using ontologies different data can be semantically related, data can be networked across domains and the concepts behind the data can be described. The process of creating an ontology including a user manual is described chapter 3.2.

Having set up an ontology corresponding to the existing AMS databases another tool is needed to finally link data from different sources to a database and vice versa. Therefore, Information Containers for Linked Document Delivery (ICDD) are used. Chapter 3.3 describes the basics on working with Information containers in the context of a prototype.

In order to implement the concepts described above, different use cases for structures and roads are described and applied in Chapter 4. This includes the work steps required to model the defined data exchange points (updates) from chapter 2.

2 Data flow during Operation Period

2.1 Data flow overview

This section explains how the proposed approach during the should be implemented during the operational period, including inspections/condition surveys, maintenance planning and collecting data on performed interventions. Special attention is given to those activities, which require data exchange and to data exchange points within them. It is assumed that at the beginning of the operation period the initial model is provided, which is derived from the so-called as-built model from the construction phase to accommodate information needed for the operational phase. This means that the IAMS is filled with data that mirror physical infrastructure after handover to the NRA. This can be the case after the initial construction but equally so after each maintenance intervention. In more general terms the IAMS needs to be updated with every physical change of an infrastructure during the operation phase. These data exchange points can be identified with a process analysis. Figure 1 shows the data flow diagram of the proposed approach used in the AMSfree project. Three important data exchange points (updates) are identified. Namely, the database will be updated with data from condition assessment as update I, maintenance plans as update II (in some cases with additional condition assessment findings), and performed maintenance actions or after the initial construction as update III. The following subsections describe the proposed three updates in detail.

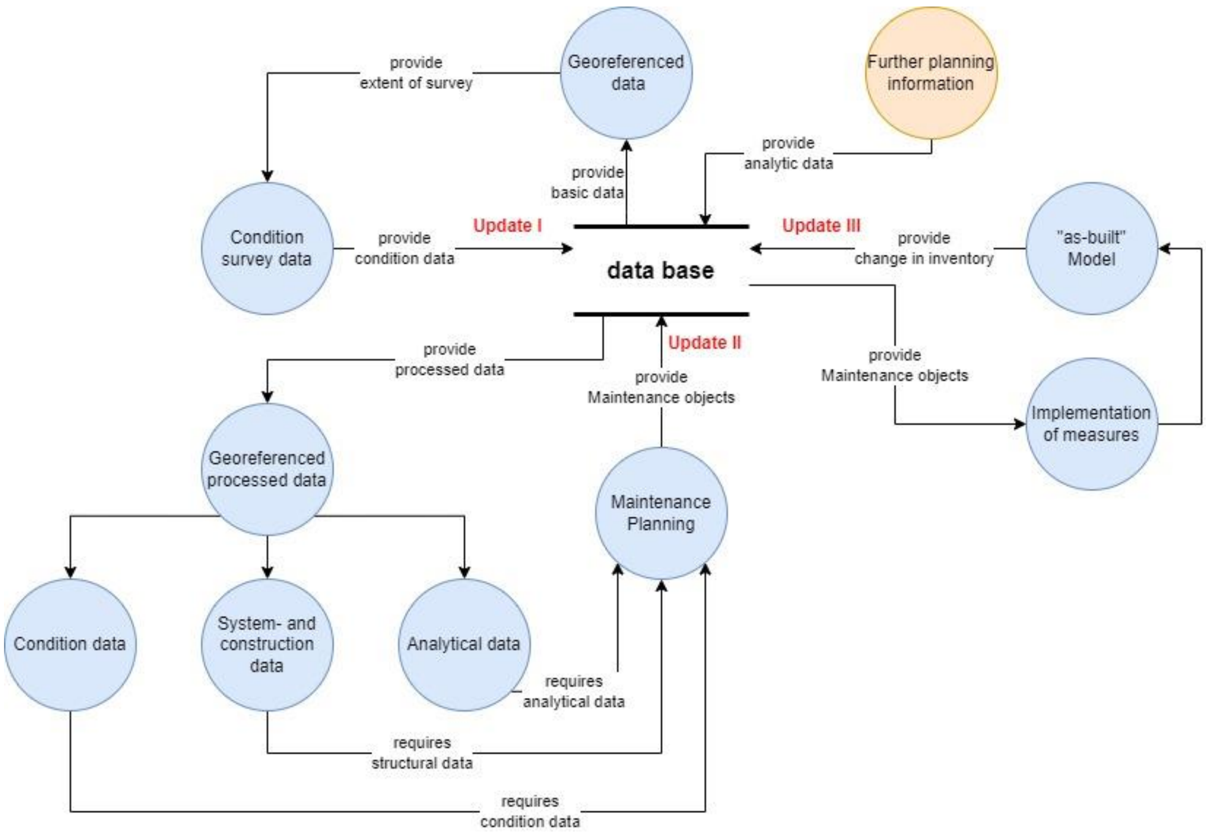


Figure 1. Data flow diagram of the proposed approach.

2.2 Description of Data Exchange Points (Updates)

As mentioned, during the operational period, three exchange points were defined at which necessary data for certain activities is provided by extracting them from a database and new data generated by these activities are stored back to database. The latter, i.e., storing newly generated data, is referred to here as an update. There are three such updates, (1) an update with the results of an inspection or condition survey and assessment, (2) an update of the prioritized maintenance interventions and (3) an update after MR&R activities or improvement interventions have been carried out.

Systematic and timely updates ensure that the database is reliable and up to date throughout the entire life span of the asset. A detailed description of the process flow is given in Report D4.1 "Definition of an Asset Management reference process" chapter 2.2.4.

2.2.1 Use-Case description

Using a fictitious road, the processes of individual updates are explained, the prerequisites are specified, and the differences to the "state-of-the-art" procedure are shown. The road progresses through a part of its life span, beginning with an upcoming condition survey. It is assumed that the road is available as an "as-built" model. The updates procedure applies analogously to bridge structures.

In the following chapters, the data exchange related to the updates is explained using the platform developed in the project.

2.2.2 Update I – Results from the inspection or condition survey and assessment

For the inspection or survey and assessment (S&A), data for the location, geometry and inventory of the asset are required. Therefore, only a partial data set from the as-built model related to the object to be inspected is required. The data set will be extracted from the database, checked-out by the road administration and transferred together with a work order to the survey and assessment team. The localisation data thus defines the perimeter of the work order. With Update I, the results of the inspection or condition survey and assessment are imported into the database. With the new information about the condition of the asset, the old conditions are superseded and archived in the database.

Differences between the inspection procedure proposed in this project and the traditional approach are as follows. In the field, the inspection procedure remains unchanged. The contractor receives the required road information digitally and records the condition of the corresponding road sections. The difference to the traditional procedure, which is defined by native format with no geometry, is that the extract from the database in native format is accompanied by the geometry in standardised vendor-free format. Depending on the type of inspection, properties can be defined by the NRA's, which are to be included in the digital inspection report and the corresponding information container.

In order to obtain a BIM model, the required granularity must be at least LOD 300, in which non-geometrical properties of the elements are included in addition to the geometry. This is necessary to link information from inspection or condition S&A required by IAMS to BIM. It should be noted that for roads the complete S&A data, for example the so-called raw-data or some of the image data are not needed in an IAMS. The complete data set should be available in a native S&A road database. The BIM model can be linked to this database retrieving only aggregated data, usually the sections' condition indices, which are needed for further maintenance planning. Nevertheless, a higher LOD extends the possibilities of the analysis, for example, lifetime considerations based on structural design methods for pavements (FGSV, 2019).

For the localisation of condition data of the pavement, linear referencing based on alignment as road axis is recommended. To localise damage as well as sensors, local element-based coordinates are recommended.

2.2.3 Update II – Update of the prioritised maintenance interventions

The process of maintenance planning requires extensive and diverse data. The data groups required can include; condition data, design and construction data, as well as other data such as traffic volume and climate data. Ideally, this data set is referred to maintenance sections transferred to an information container so that maintenance planning can be carried out properly. This requires access to the condition database as well as to the planning and inventory data in the IAMS database. With an MR&R software, the maintenance plans and the prioritisation lists can be generated. Detailed information is given in report 4.1 for the process and reports 4.2 and 4.3 for the required property sets. It should be noted that the data demand depends on the MR&R software.

After completing the MR&R plan with further considerations, such as practical feasibility, the plan is written back with a further information container and delivered to the AMS-Database.

2.2.4 Update III – Update of the “as-built” model

For asset management, it is vital to update the as-built model after an MR&R intervention. It is not necessary to transfer information from the different planning or execution steps (e. g. planning model, construction model) to the asset management database, as they are used project-related in the BIM authoring software or in the BIM coordination software.

The transfer of the as-built model is referred to here as Update III. The new as-built model contains the objects that are altered by a MR&R intervention.

Replaced or renewed elements are updated in the BIM-Model. For this purpose, the old elements are clipped out of the BIM and archived. New elements are stored in the BIM using information containers. Even if an element is only renewed, the element is replaced in the BIM because the material properties change.

Certain types of construction work as part of the maintenance of structures can lead to major changes in the asset geometry. Examples of these works are the replacement or addition of elements (e. g., replacement of a precast girder and widening of the bridge). These changes cannot be done with the proposed approach. The information containers cannot store information about geometry changes. However, there are other ways to solve this problem. The simple approach that does not interfere with the proposed use of information containers is to use so-called timestamps. This means that every time the geometry of an asset changes, the asset is linked to the new BIM model representing the new geometry. Each replaced element would be 'time stamped' so that the current state of the asset is represented by a model including those elements with the latest timestamp. The elements of the original model are given the date of commissioning or the date when the first BIM model was created and applied to the asset.

3 Workflows and Software Tools

3.1 Working with BIM models

This chapter describes basic information on BIM. This includes a brief description of the most important aspects and software tools in the context of BIM. The Industry Foundation Classes (IFC) define file formats with regard to data exchange (see chapter 3.1.1). Depending on the point in time during the lifespan of an asset different BIM models are used. This is described by the BIM creation workflow in chapter 3.1.2. In order to allocate information within a BIM model based on fragmentation (chapter 3.1.3) methods to localise sensor monitoring data (chapter 3.1.4), localising detected damages during condition inspections (chapter 3.1.5), and visualisation of maintenance planning (chapter 3.1.6) are described.

3.1.1 Industry Foundation Classes (IFC)

The data exchange and linking between BIM models and IAMSs is significantly facilitated by using the IFC file format developed by buildingSMART International (bSI). Being neutral, this format provides free two-directional access to all parts of the model. The semantic quality of the BIM model in the IFC representation depends on the IFC schema used for the IFC export. The latest official schemas are IFC4 ADD2 TC1 (ISO 16739-1:2018) and IFC2x3 TC1 (ISO 16739:2005). These schemas mainly define building-related concepts. Nevertheless, quite intensive activities on extending the official schemas are currently in progress. The soon-to-be-released IFC 4.3 will provide definitions of all the relevant concepts for the infrastructure domain. Geometry-based, the proposed approach is applicable on any IFC file, regardless of the schema version. The asset management information flowing between IAMSs and BIMs is mainly provided by the information container (see chapter 3.3), not the IFC semantics (see chapter 3.2). The exception is the condition assessment data stored in the IFC, using the entities defined in the latest IFC schema extensions. However, these exceptions are addressed in the prototype software processing the input IFC file, thus not affecting the BIM handover requirements.

3.1.2 BIM creation workflow

The BIM modelling approach should be selected depending on the type of the model to be created. The following three cases are considered:

- as-designed,
- as-built,
- and as-is BIM modelling.

BIMs are usually produced in the design stage and updated later due to changes during the later construction project phases. The final version of a BIM should reflect the condition of a real asset at the moment of commissioning. This type of BIM is called “as-built BIM”. However, the typical workflow in the construction industry does not imply such a prompt up-date of the project documentation in the late project phases.

Instead, the final BIM usually corresponds to a particular late design phase or a construction phase. This type of BIM is called “as-designed BIM” resp. as-built BIM, which will be handed over to the IAMS.

Whereas the two described types of BIM refer to the starting point of the asset’s life span (whether in the design or in the construction phase), the as-is BIM refers to the current state of the asset. Its purpose is to reflect the geometric changes of the asset caused by deterioration or maintenance actions. Creating such a model is more of an update of the as-built one, and it requires either the inspection field data or the design documentation of the maintenance works. Additionally, redundant information from the design phase will be removed or archived.

All created models (as-designed BIM model, as-built BIM model and as-is BIM model) are available individually and can be loaded individually via a prototype (see also chapter 2.2.4).

3.1.2.1 As-designed BIM modelling

The as-designed BIM model is the most common type of BIM model as it is the deliverable of the design phase in each construction project implemented using the BIM technology. The unique standardised modelling workflow still does not exist. Instead, each BIM modelling engineering company develops its own modelling workflows, which are repeatedly improved after each delivered model. Assuming that the readers are most familiar with the modelling concepts of this basic BIM type, it will not be further discussed.

3.1.2.2 As-built BIM modelling

The BIM, which is to be handed over to the IAMS, can be either the as-designed, or the as-built BIM, or something in between. The as-built BIM handover is highly recommended to use. Nevertheless, the IAMS will also benefit from having the geometry of the as-designed model. Even out-of-date geometry is better than no geometry at all. Moreover, the asset management process itself includes model updates. Therefore, the as-designed BIM will, after being used by the IAMS for some time, get closer to the as-built one and, eventually, to the as-is BIM. According to experience, the as-built model from the construction phase contains more information than is needed in the operation period. In this respect, it must be decided which information is to be transferred for the AMS during the operation period.

The as-built model is modelled in the same way as the as-planned model by using CAD software tools (see chapter 3.1.2.4). The geometry of each element represents the actual result of the construction process. Additionally, the specific properties of each element are described via the property sets.

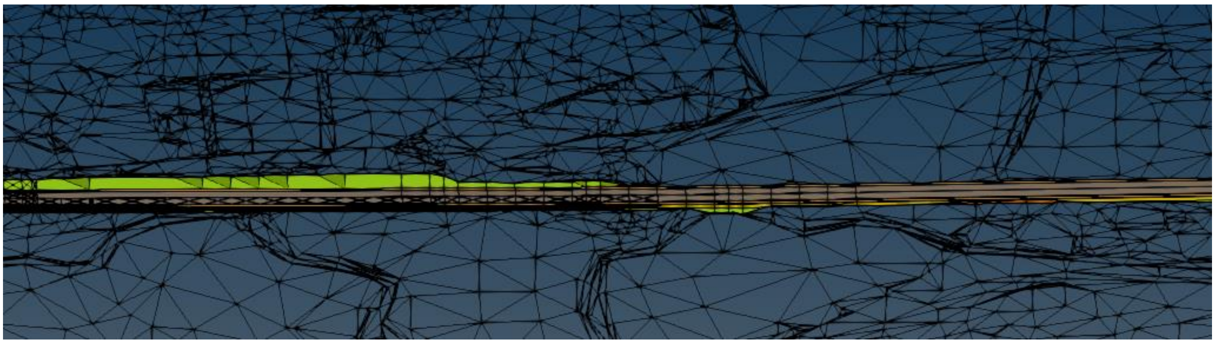


Figure 2. Example of an as-built model of a road section

The required BIM Level of Detail (LOD) depends on the specific data exchange points, also referred to as updates in the previous reports.

3.1.2.3 As-is BIM modelling

The condition of the asset will change during its lifetime. The current condition state can be recorded and documented, for example, in the course of condition surveys and inspections. Furthermore, there are changes that are caused by performed maintenance interventions. The as-is BIM model reflects the actual condition of the asset.

3.1.2.4 BIM modelling software

In the context of Building information modelling (BIM) software it can be distinguished between authoring software, coordination software and Common Data Environments.

Building information modelling (BIM) software includes computer-aided design (CAD software) products used commonly within the architecture and construction industries. Many of these products offer tools and libraries specifically targeted toward construction, including mechanical, electrical, and plumbing (MEP) and building information modelling (BIM). The most widely used BIM software currently in sue include;

- Revit
- Civil 3D
- Allplan
- ArchiCAD
- CARD1 (for road design)
- proVI (for road design)
- VESTRA
- Tekla

Most of the above-mentioned BIM modelling software provide for export using IFC 4.1. With regard to the alignment of roads, IFC 4.1 does not offer satisfying solutions.

During the design and construction phase of an asset many different parties are involved who update the original planning and document the construction process often simultaneously. In order to improve the coordination between all parties, special software is used i.e., coordination software.

The goal of the coordination software is to combine this data into a single, comprehensive, multidisciplinary model that can identify the potential collisions (clashes) across these different sources. These problems and inconsistencies are detected early on and are then successfully managed by the responsible teams. This helps in mitigating problems in the multi-level design that might arise in the future stages of the project. Some of the commonly used coordination software include Navisworks, Solibri and Bexel Manager.

Common Data Environment (CDE) is a platform for data and information exchange during project execution. It represents a medium through which the project participants transfer and update project models, contracts, and other documents. This takes effect through a connected system like the internet, intranet, or more often using cloud-based storage solutions. By using a CDE, every project participant has access to the most recent version of the project data, which results in the more effective delivery of project results. Ordinary cloud-based storage solutions such as Google Drive, SharePoint, and Dropbox are commonly used as data exchange platforms. For more advanced usage and better convenience in the project and quality management, BIM 360 (Autodesk Build) can be used, as it also offers collision detection features and provides the availability to conveniently view the project models online.

3.1.3 BIM fragmentation

In order to map information on sub-elements as precisely as possible, an asset needs to be fragmented into components. The fragmentation density corresponds to the depth of the deepest and most detailed element classification hierarchy (ontology) (see chapter 3.2). Figure 3 shows an example of a decomposed abutment into sub-elements.

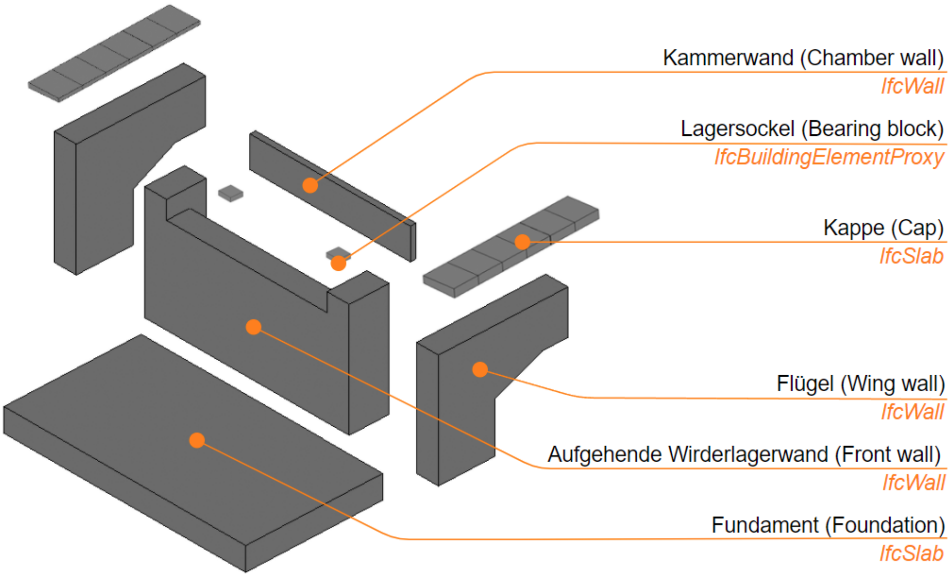


Figure 3. Example of decomposed abutment into sub-elements (Isailović, Hajdin in preparation)

3.1.4 Damage localisation and sensor information modelling

Inspection findings are not inserted into the BIM model but just externally referenced. For instance, the inspection report is stored externally (e.g., for structures in the BMS database) and referenced in the BIM model only by location information (URI). The IFC schema offers two options for external referencing. The first one is by using *IfcDocumentInformation* (which offers various attributes for storing the linked document metadata) and URI. The other option is using *IfcDocumentReference*. This option references the document without metadata.

Damage modelling

Detected damages can be assigned to the as-built IFC model by addressing the element geometry (Isailović, Hajdin in preparation*).* In the example shown in Figure 4, detected damage was assigned to the as-built model of a structure by using *IfcSurfaceFeatures* and defining its coordinates. The geometric dimensions are defined by using the *Pset ProvisionForVoid.* Figure 4 shows the defined bridge damage and its geometric dimensions in an IFC viewer software.

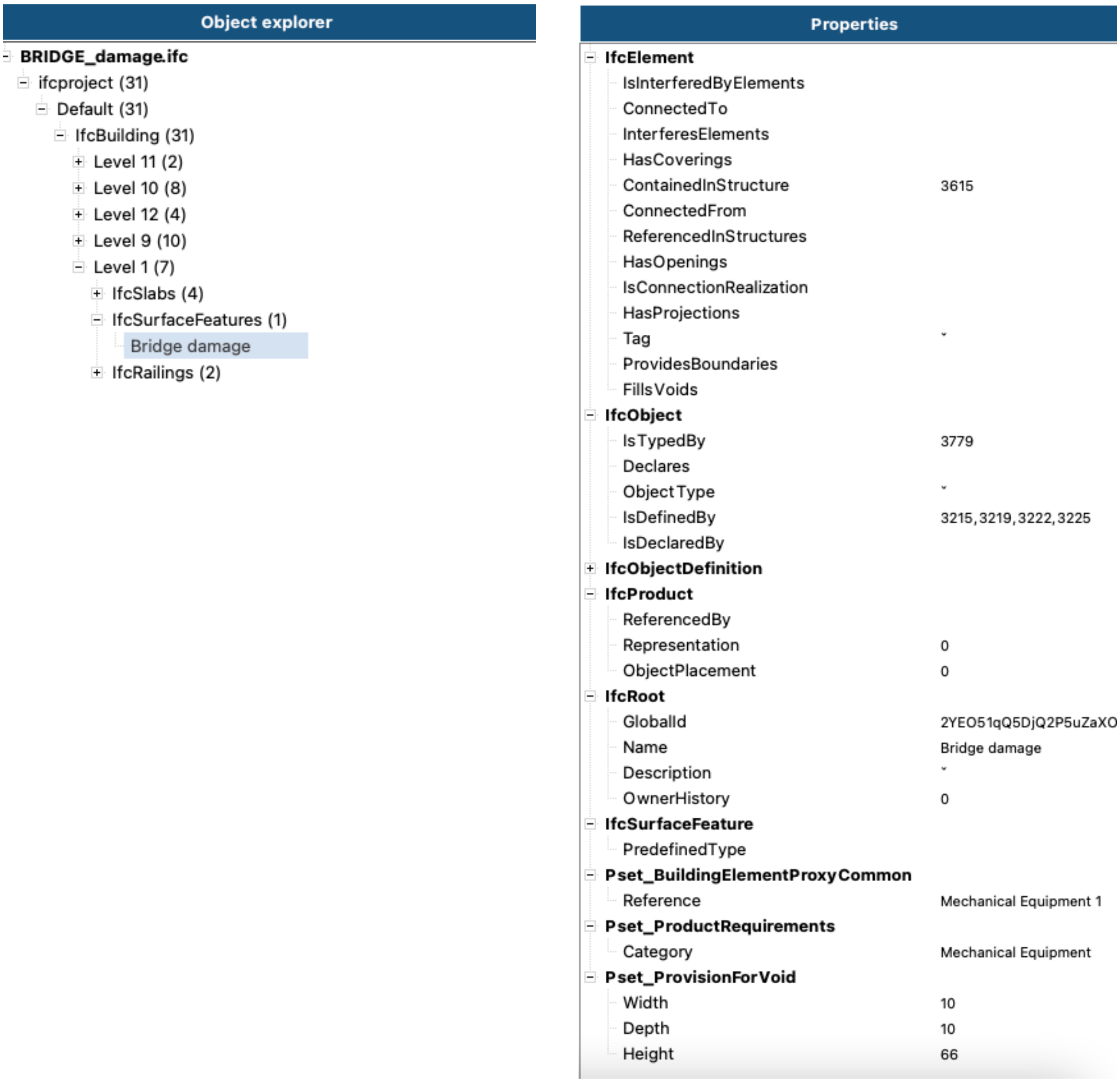


Figure 4. Defining bridge damage including its geometric dimensions

Sensor modelling

In order to assign a sensor geometrically, *IfcSensors* is used. The geometric dimensions are defined by using the *Pset ProvisionForVoid.* Figure 5 shows the defined sensor and its properties in an IFC viewer software.

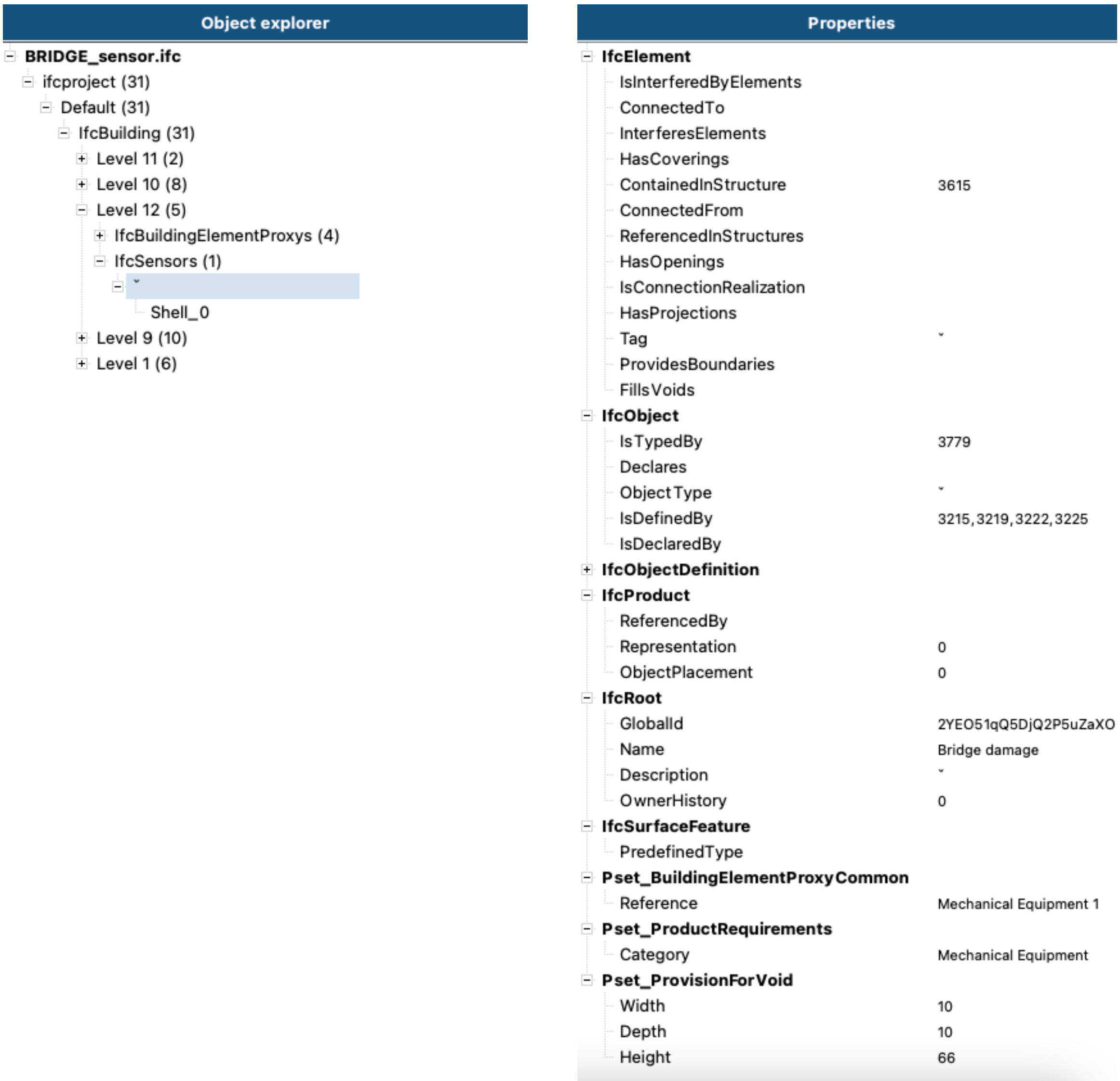


Figure 5. Defining a sensor including its properties

In the example shown in Figure 6 and 7, a sensor was placed on the lower side of a beam. The position and geometric dimensions of the sensor are modelled by its vertices which are described with the coordinates of x, y and z axis.

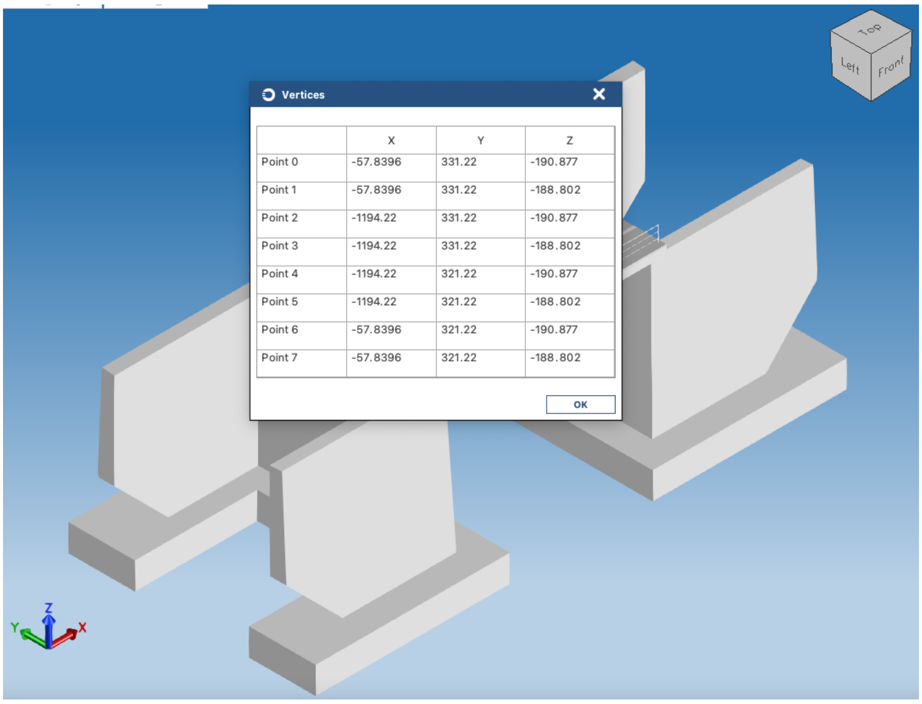


Figure 6. Description of location and geometry of a sensor by defining its vertices

Figure 7 shows the modelled strain gauges sensor on the bottom side of the beam.

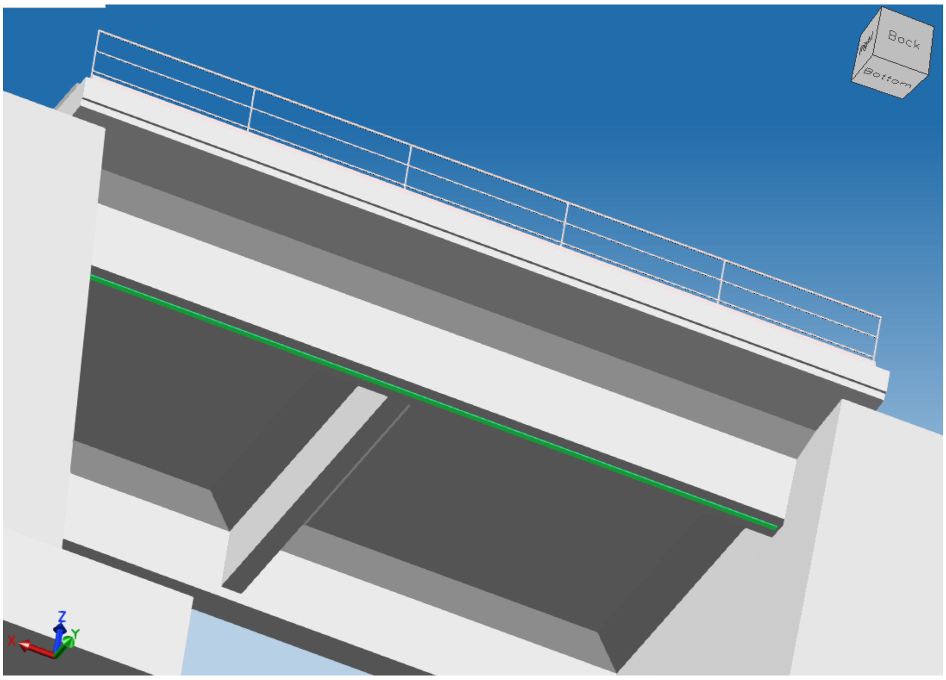


Figure 7. Located strain gauges sensor on the bottom of a beam of the bridge

3.1.5 S&A Survey and Assessment Section Modelling

Based on the as-built model of the pavement, the survey information for the surface characteristics is modelled. For the display of the S&A results, a virtual layer is placed on the structure or road section by using IFCLayer (Figure 8). This means that information on surface condition of roads is not directly linked to the roads elements but are linked to the additional fictive surface layer.

Property sets are available for the survey results, which can be adapted to different pavement characteristics (e.g., road surface, deflection/bearing capacity). The property sets can be found in detail in the project report D4.2. With these, the survey information can be entered and stored uniformly in the container.

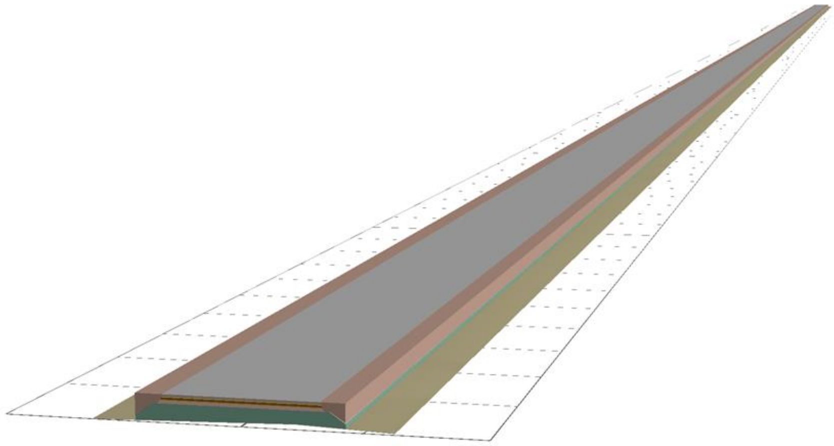


Figure 8. Road section with virtual layer

3.1.6 Maintenance Planning Section modelling

Similar to the modelling of the inspection information, the maintenance planning information for the visualisation is also modelled in the virtual layer, See **Fehler! Verweisquelle konnte nicht gefunden werden.**. The maintenance planning information, i.e., which intervention types are planned, when they are to be carried out and other relevant information such as cost estimation and/or applicable material properties, are entered into the container via an existing property set. The property sets can be found in detail in the project eport D4.2.

The maintenance planning information for structures is visualised by highlighting the structural elements that require maintenance.

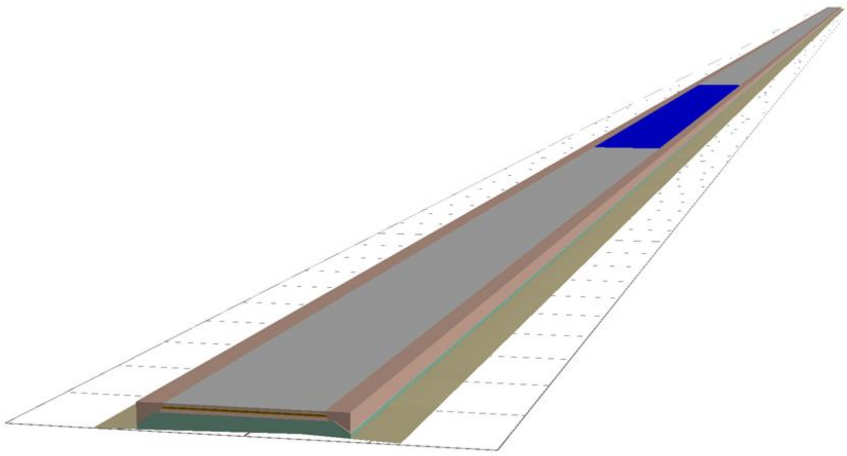


Figure 9. MR&R Section

Using the template structure (Figure 10), data from different maintenance scenarios can be linked to the model in a standardised way. This ensures seamless data transfer to different users. In the first sequence of the template structure the meta information of the road is addressed. In the sequence the elements for meta information are predefined with type and name of the information. The elements in the next sequence describe meta information related to maintenance planning. For the maintenance program of a road section different sequences such as the type of road section, the type of measure, and the type of maintenance program are included.

Meta information of the road

Meta information of maintenance planning

Maintenance program of road section

```xml
<?xml version="1.0" encoding="utf-8"?>
<xs:schema targetNamespace="http://amsfree.eu/MaintenanceProgram"
    elementFormDefault="qualified"
    xmlns="http://amsfree.eu/MaintenanceProgram"
    xmlns:mstns="http://amsfree.eu/MaintenanceProgram"
    xmlns:xs="http://www.w3.org/2001/XMLSchema"
>
  <xs:element name="MaintenanceProgram" type="MaintenanceProgramType"/>
  <xs:complexType name="metadataPavementType" mixed="true">
    <xs:sequence>
      <xs:element type="xs:string" name="adminAuthority"/>
      <xs:element type="xs:string" name="roadID"/>
      <xs:element type="xs:string" name="roadName"/>
      <xs:element type="xs:string" name="roadDesign"/>
      <xs:element type="xs:gYear" name="constructionYear"/>
      <xs:element type="xs:string" name="pavementTypeMaterial"/>
    </xs:sequence>
  </xs:complexType>
  <xs:complexType name="metaDataMaintenancePlanType" mixed="true">
    <xs:sequence>
      <xs:element type="xs:string" name="consultEngineer"/>
      <xs:element type="xs:string" name="consultDate"/>
    </xs:sequence>
  </xs:complexType>
  <xs:complexType name="headerType" mixed="true">
    <xs:sequence>
      <xs:element type="xs:short" name="MaintenanceYear"/>
      <xs:element type="metadataPavementType" name="metadataPavement"/>
      <xs:element type="metaDataMaintenancePlanType" name="metaDataMaintenancePlan"/>
    </xs:sequence>
  </xs:complexType>
  <xs:complexType name="roadSectionType" mixed="true">
    <xs:sequence>
      <xs:element type="xs:string" name="typeMeasure"/>
      <xs:element type="xs:string" name="descriptionMeasure"/>
      <xs:element type="xs:gYear" name="measureYear"/>
      <xs:element type="xs:float" name="measureEstimatedCost"/>
    </xs:sequence>
    <xs:attribute type="xs:float" name="startPoint" use="optional"/>
    <xs:attribute type="xs:float" name="endPoint" use="optional"/>
  </xs:complexType>
  <xs:complexType name="measureType">
    <xs:sequence>
      <xs:element type="roadSectionType" name="roadSection" maxOccurs="unbounded" minOccurs="0"/>
    </xs:sequence>
  </xs:complexType>
  <xs:complexType name="tableType">
    <xs:sequence>
      <xs:element type="measureType" name="measure"/>
    </xs:sequence>
  </xs:complexType>
  <xs:complexType name="MaintenanceProgramType">
    <xs:sequence>
      <xs:element type="headerType" name="header"/>
      <xs:element type="tableType" name="table"/>
    </xs:sequence>
  </xs:complexType>
</xs:schema>
```

Figure 10. Maintenance plan information as XML schema

3.2 Working with Ontologies

Beside the IFC model, semantic information can also be digitised and stored as instances using ontology. Ontologies are used to provide data schemas and are described by a document or a file that formally defines the relations among terms. This is needed to define how to process and interpret data. By using ontologies different data can be semantically related, data can be linked across domains and the concepts behind the data can be described. Furthermore, the linking among data from different sources can also be realized. The ontology is developed according to the needs of the asset owner. In this report, we will give a short overview about the creation of an owl ontology. The focus of the report is mainly on the use of existing ontology, for instance, EUROTL for Infrastructure developed by INTERLINK project (O'Keeffe et al.2018). That means, how the user can create the data as an instance of a domain ontology using an appropriate tool.

3.2.1 Ontology creation

A domain ontology, which has to match the needs of the asset owner, can be defined by Resource Definition Frameworks (RDFs) or Web Ontology Language (OWL). To define an ontology, these computer languages are suggested by the World Wide Web Consortium (W3C). However, regardless of the computer languages in which they are expressed the ontology formally organizes the domain under consideration by defining concepts and relations between them. In more concrete terms the domain ontology used by an asset owner must describe sufficiently well the transformation of its infrastructure over time. To this end, it is common that ontologies include classes, properties and constraints included in each class and relations between classes. With a clear picture of domain ontology and the context, one can define ontology in any form even purely textual. The formal description of ontology can be provided by UML (Unified Modelling Language). With a documented and visualized scope of the required domain ontology, the tools "TopBraid Composer" and "Protégé" can then be used for definition of an OWL ontology.

In the AMSfree project *TopBraid Composer* was used to author classes and properties of a domain ontology. TopBraid Composer provides a dynamic input formula related to the generation process of an ontology. First of all, on the formular "Ontology Overview", the base URI and the prefix of the ontology can be defined as shown in Figure 11. Further information about the ontology e.g., description, authors, and comments, can be added using "Resource Form" as shown in Figure 12. In the same way, the information of a class or a property can also be added easily using this form. For an ontology based on OWL, the classes should be generated as subclass of the *owl:Thing* as shown in Figure 13. In the new class, data property and object property can also be created as subclasses of the *owl:DatatypeProperty* and *owl:ObjectProperty*. The constraint such as number of the linked properties (candidate), the subject class or property of a triple (domain) and the object class or property of a triple (rang) should also be considered during the ontology definition (see **Fehler! Verweisquelle konnte nicht gefunden werden.**).

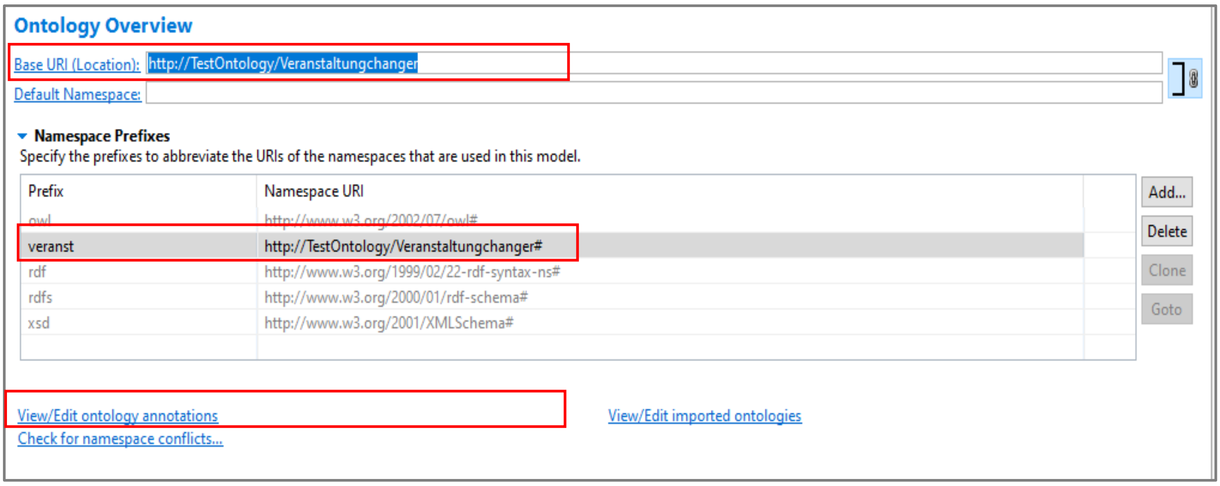


Figure 11. Ontology overview (Screenshot of TopBraid)

Figure 12. Resource Form (Screenshot of TopBraid)

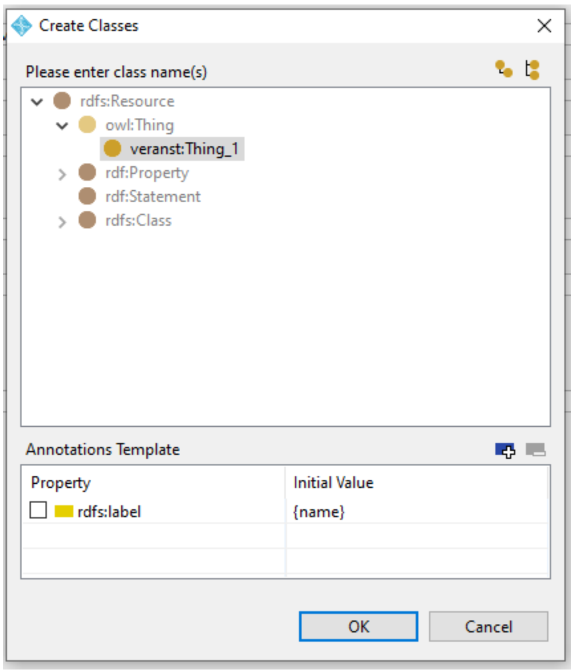


Figure 13. Creation new class of an ontology as subclass of owl:Thing (Screenshot of TopBraid)

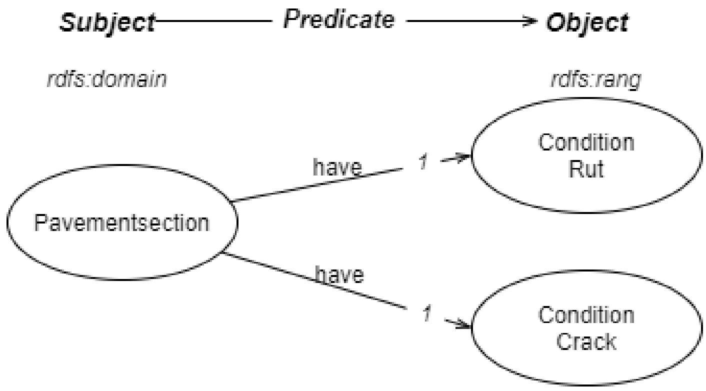


Figure 14. Semantic triples with example of the pavement conditions

3.2.2 Semantic information using domain ontology

Once the ontology is defined, the instances of ontology class and property can also be created by using TopBraid Composer. With the defined relations between the classes and properties in the ontology, the instances and their relationships are stored as triples like “subject - predicate - object”. The triples can be recorded in data files with XML, Turtl or RDFs format. The links between the cross-ontology instances can be created within the information container. After the short overview about the creation of an ontology and instances, the use of an existing ontology is more important for an engineer’s activities. An example for a pavement condition survey using the European Road OTL framework (EUROTL) for data collection will be shown. The EUROTL framework provides core definitions which cover basis classes considering the infrastructure asset life span shown in Figure 15. This core definitions can be extended or linked to further existing domain ontologies (e.g. OKSTRA OWL, IFC OWL).

In the example in Figure 16, the related data of a pavement condition survey will be collected as instances of the ontology. The main parts of the survey data are:

- the activity
- road section
- condition of the section

The instances of each part can be created by following class of the EUROTL:

- the activity as instance of class “InspectionActivity”
- road section as instance of class “Lane”
- condition of the section as instance of class “Condition”

Once the activity and road section are described as instances of the ontology, more data can be captured and related to the defined road sections using available properties. If the existing ontology does not cover the whole information requirement, extensions of the ontology should be discussed and created if necessary.

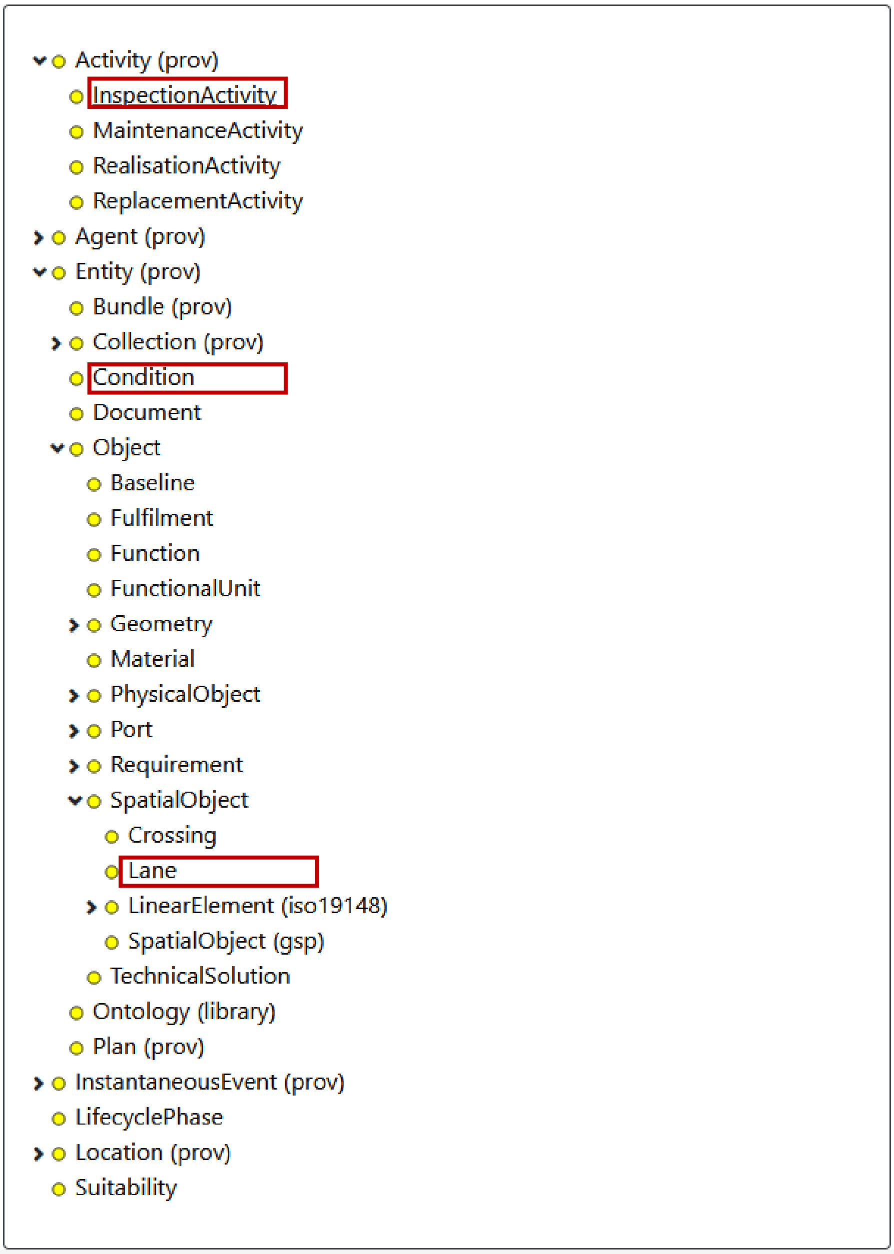


Figure 15. Overview of EUROTL with highlighted classes for the example (Screenshot of TopBraid)

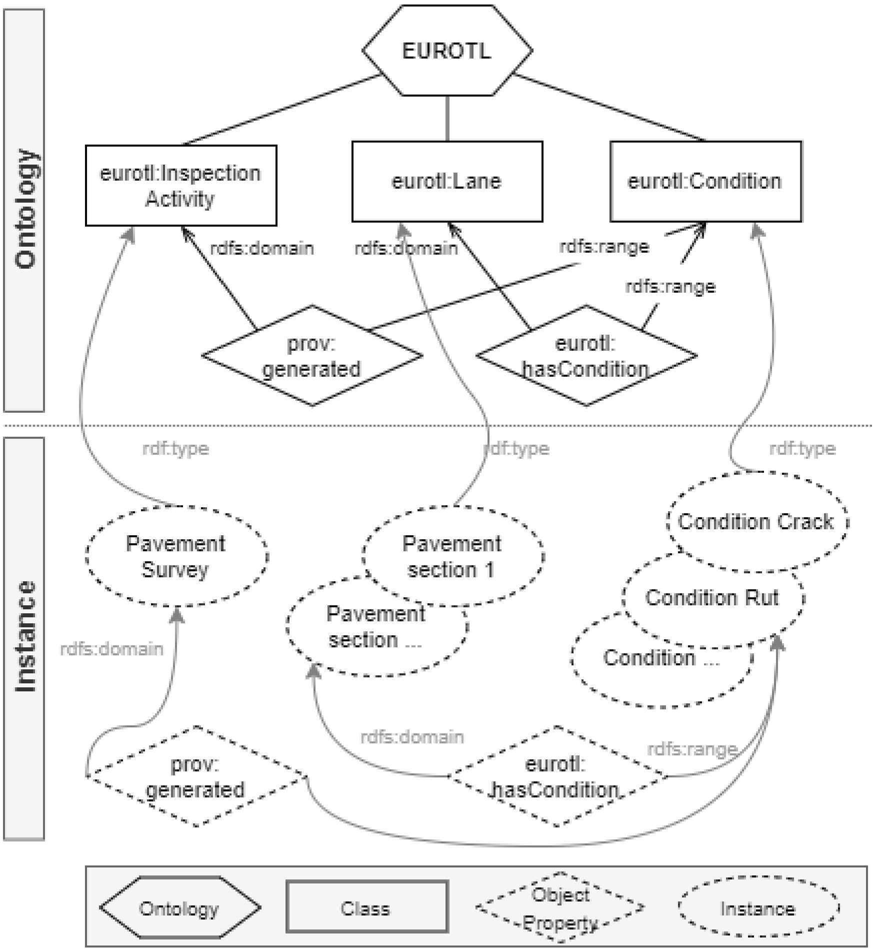


Figure 16: Example for instances of ontology EUROTL

3.3 Working with Information Containers

The information container is a tool with which information from different sources can be transferred. The information container is not an additional file format, but an organisational system or a platform through which different data sources are managed by means of links and dependencies. In the AMSfree project, this prototype platform can be used via a web application in the web browser. In this way, data such as BIM models, the condition data, the operational data and other information can be uploaded and are brought together and linked via the container (Figure 17). The information container can be created individually for each application in order to create fields in the container that suit the requirements. Via the platform these fields of the container are filled with the data to be transferred and linked. A detailed description of the technical functionality can be found in Report 3.2 Chapter 3.3 Information Containers for Linked Document Delivery.

Figure 17. Graphical representation of the Information Container for Linked Document Delivery

By working with Information Containers, there is no need for a standardised format for data exchange. The Information Container establishes links to the different formats and can also be used to save changes to the original format. NRAs do not have to make any adjustments to their system to use the container. Only the mapping rules about the ontology and the structure of the existing AMS database must be defined to create the Information Container (Figure 18). Detailed specifications, as property sets and ontologies of the Information Container for Road Maintenance Planning and Bridge Condition Assessment, are explained in Report 4.2.

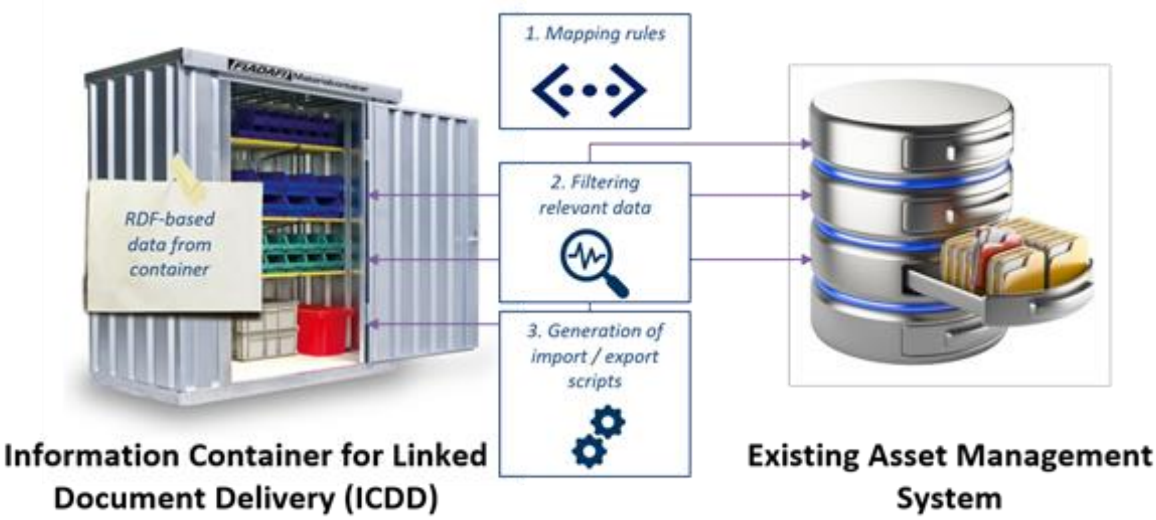


Figure 18. Graphical representation of the data exchange between ICDD and AMS database

In addition to managing data sources, SPARQL can be used to query, filter and output information. This makes it possible to work with all data sources simultaneously, regardless of the data format.

3.3.1 Information Container overview

Very often, data in different formats have to be exchanged. In certain cases, it is not useful to convert all data into another format. For example, a conversion is not possible due to restrictions of the target format, or the software system only supports certain interfaces. It has also been shown that it is not always useful to exchange all information with the help of the IFC (Report D 5.2).

The ISO 21597 standard wasdeveloped in response to the need of the construction industry to handle multiple documents as one information delivery or data drop. The ISO 21597 standard provides a specification for an information container. It enables a uniform approach to the way information is organised in data drops, providing a means to create semantic links between concepts in separate documents; it also provides a basis for additional functionality that allows a container to be customised for a given purpose, facilitating innovative software development that still conforms to the standard. The container format includes a header file and optional link files that define relationships by including references to the documents, or to elements within them. The header file uniquely identifies the container and its contractual or collaborative intention. This information is defined using the RDF and OWL semantic web standards. The header file, along with any additional RDF/OWL files or resources, forms a suite that may be directly queried by software. Where it includes link references into the content of documents that do not support standardized querying mechanisms, their resolution may depend on third party interpreters. Alternatively, the link references may be interpreted by the recipient applications or reviewed interactively by the recipient. The format can also be used to deliver multiple versions of the same document with the ability to convey the known differences or priority between them.

Within the scope of this task, a concept for the definition of information containers for data exchange with legacy IAMS is developed. Existing national data formats (e. g. OKSTRA, Interlis2) will be linked with the IFC format. It has to be documented which data is transported via which format (e.g., IFC, OKSTRA, Interlis2), which data is mapped to each other and how, and which consistency checks are necessary. For the creation of information containers according to ISO 21597, a framework developed by project partner RUB is adopted.

The information containers are defined based on ISO 21597 and can therefore be used or extended easily and without restrictions by other users. Information container specifications are made available in neutral IDD format on the project website without restrictions to the CEDR members and the market. Thus, Information containers can be used when there is a national need for more information and to interact with existing legacy systems. This is a rather practical approach and allows the reuse of existing data formats. Of course, it must be ensured that the different systems can read and interpret the files contained in the container.

Once the IFC file representing the infrastructure asset is handed over to the NRA. The data transfer between IFC and IAMS is enabled by means of the information containers. An Information Container for linked Document Delivery (ICDD, ISO 21597) is the data structure intended for handling a variety of interrelated documents. The documents in the container are organised, and the data is linked according to the ICDD specification. All the information stored in the container is contextualised by means of ontologies, also the part of a container. The generic ICDD consists of four components (see Figure 19):

- index.rdf (description of the container content)
- Ontology resources folder (ontology storage).
- Payload documents folder (documents storage)
- Payload triples folder (links storage)

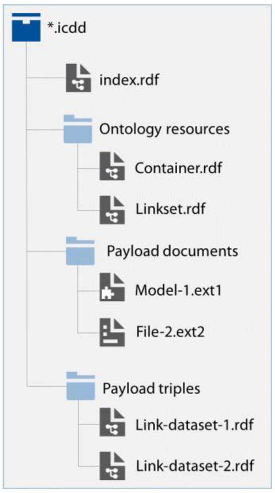


Figure 19. ICDD components (Hagedorn 2018).

A detailed description of the ICDD is provided in the Report D3.2.

3.3.1.1 Definition of container content

The ontologies represent certain classes. Container.rdf and LinkSet.rdf are the standard ontologies for defining the documents and the links of the container. AsphaltCondition.rdf is an ontology to capture the condition of roads comprising pavement construction. Since the evaluation of the condition of pavement is carried out according to national standards, the ontology must be adapted to the national framework. The properties can be extended country-specifically by an ontology for each asset owner. MaintenanceProgram.rdf is an ontology to describe the recommended actions related to specific locations. This is shown in Figure 20, where also the difference of the Maintenance Plan and the Maintenance Program are displayed. On the left side the *MaintenanceProgrsam.xsd* is a xsd-file, which is a structure template for sml-files, on the right side the *MaintenanceProgrsam.xml.* Additionaly the Payload triples are extended with the *RoadSectionMaintenance.rdf*.

Exchange Requirements Model		
Name:	Road Maintenance Plan	
Identifier:	ER1_ICDD_Maintenance_Plan	
Description:	**Name**	**Type**
Index:		
	Index.rdf	rdf
Ontology Resources:		
	Container.rdf	rdf
	LinkSet.rdf	rdf
	AsphaltCondition.rdf	rdf
	MaintenanceProgram.rdf	rdf
Payload Dcuments:		
	RoadModel.ifc	ifc
	RoadSections.ifc	ifc
	Condition.xml	xml
	MaintenanceProgram.xsd	xsd
Payload triples:		
	RoadSectionCondition.rdf	rdf

Exchange Requirements Model		
Name:	Road Maintenance Program	
Identifier:	ER2_ICDD_Maintenance_Program	
Description:	**Name**	**Type**
Index:		
	Index.rdf	rdf
Ontology Resources:		
	Container.rdf	rdf
	LinkSet.rdf	rdf
	AsphaltCondition.rdf	rdf
	MaintenanceProgram.rdf	rdf
Payload Dcuments:		
	RoadModel.ifc	ifc
	RoadSections.ifc	ifc
	Condition.xml	xml
	MaintenanceProgram.xml	xml
Payload triples:		
	RoadSectionCondition.rdf	rdf
	RoadSectionMaintenance.rdf	rdf

Figure 20. Information containers for maintenance planning of roads (RUB 2021)

To relate the ontologies with IFC models and infrastructure asset management concepts (payload documents), an RDF-file is needed. It contains the links between the road sections and the condition data using the payload documents.

IFC creation

To create an IFC file of the model, a BIM-compatible model must be created with modelling software such as 'Revit' or 'Allplan'. The model can then be exported as an IFC model. The BIM-model describes the as-built model of the road/bridge using IFC format. The model contains all relevant geometric and semantic information required for maintenance planning. Furthermore, planning parameters (i.e., traffic volume, climate conditions) are attached to corresponding model elements as additional properties. The road model with its geometry will not be modified during maintenance planning. Additional information to be managed later in the asset management system is added to the BIM model as external information or additional properties.

3.3.1.2 As-is model creation

The as-is model is an update of the existing as-built model after a Condition survey and Assessment or a MR&R action. This can result in not only material but also geometric changes. Therefore, the as-built model must also be geometrically modified. For this purpose, the changed elements are removed from the existing model and attributed with an expiry date, whereby the past geometry is archived. The current properties of the element are added as a new model. The information container joins the models together and displays them as one as-is Model.

3.3.2 Prototype of an ICDD-Platform

The development of a web-based ICDD-Platform is described. For the organisation of the data and the ICDD, the platform should give a function for the creation of projects, in which the individual updates are mapped and filed within the information containers. Furthermore, there must be the functionality to edit, modify and delete containers and container content. The following chapters describe the prototype requirements in detail.

3.3.2.1 Data Upload

In the beginning, a project must be created in at the ICDD Platform. This can be found in the "Project List". By clicking on the name, the project is opened. Several information containers can be created in a project, either directly on the website or by uploading them. Templates for Asset Management Maintenance and Inspection are stored on the website and can be selected when creating the project.

The information container can now be filled. For that, the container must be opened. The structure of the container can be found in the Explorer on the left. The content window contains the content of the files and the container dashboard with information about the container. In addition, it offers five options for editing the container content, including uploading. With “Participants”, contributors i.e., persons working on the container can be added. An ontology or a payload triple can be added at Ontologies by entering a web URL or uploading a file. The Documents field offers the possibility to add internal documents, external documents, database connections and folders. With “Add Linkset” a new linkset can be created in the Payload triples folder, only a name has to be entered. This linkset can be extended in the Payload triples folder. A SPARQL query can be written under “Query”. The properties contain the metadata of the container, which was specified when the container was created. The metadata can be changed and updated here. In addition to the properties that are displayed within the container, there is also the IFC viewer. The IFC viewer displays the models.

3.3.3 Data linking in the ICDD

With the ICDD platform developed in this research project, which is available as a prototype (https://icdd.vm.rub.de/amsfree/), information containers can be used to transfer documents. For this purpose, documents are loaded into the created containers. This is done in three categories; ontology resources, payload documents and payload triples. In the ontology resources, the ontology of the container, the linkset and the structure of the additional data recorded are loaded. The payload documents are the IFC models and the data to be captured (condition, maintenance plan and performed maintenance interventions). The payload triples store the predefined payload documents. Thus, all documents are loaded in the container. The data is now linked to each other through the linksets.

3.3.4 Query of data via SPARQL

Queries of the data can then be undertaken using SPARQL (SPARQL Protocol and RDF Query Language). The query language developed by W3C has an SQL-like language for RDF graph data. The Turtle syntax as well as the RDF syntax can be used to formulate query commands. Figure 21 shows a simple syntax example of a SPARQL query in Turtle.

```
PREFIX pref:<URI>
SELECT ?var1 ?var2 ?var3
WHERE {
?var1 pref:klasse ?var2 .
?var2 pref:property ?var3.
}
```

Figure 21. Turtle Syntax example of a SPARQL query

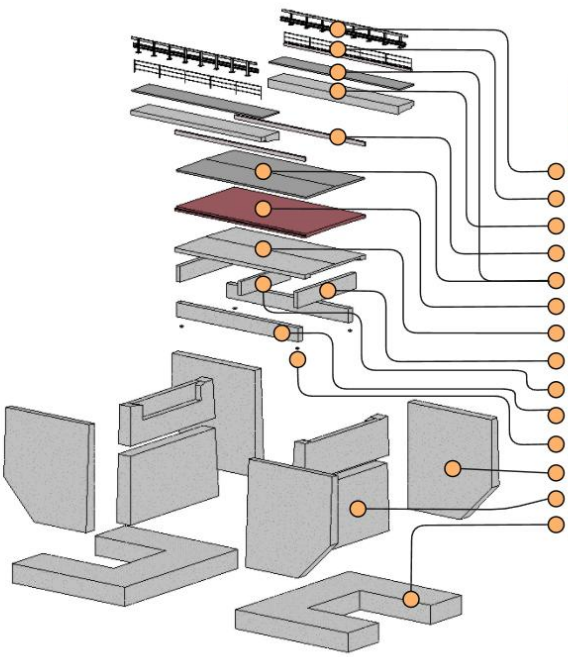
4 Use Cases

4.1 *Introduction*

In order to show the proposed concepts different use cases for structures and roads are shown in the following chapter.

4.2 *Use Case 1: Structures*

As described in chapter 3.1.3 the level of detail of the modelled geometry of each element is essential in order to map properties accurate to detail. To show how the proposed concept applies in practice, the German BMS, ASB-ING, is used. ASB-ING's object classification is a hierarchical catalogue with a huge number of object type categories. The model is disassembled, and each bridge element and sub-element is associated with the corresponding ASB-ING catalogue type. The orange labels in Figure 22 are the IFC entity types representing the abutment sub-elements. They are shown in Figure 22, only to indicate that each sub-element is an easily referenced separate BIM element.



ID ASB-ING	Bezeichnung	Designation
130022112110000	Schutzplanke	Fence
130022121210000	Füllstabgeländer	Handrail
130011131340000	Kragarm	Cantilever
130021810000000	Bordstein	Curb
130022510000000 / 130022520000000	Fahrbahn-/ Gehwegbelag	Wearing layer
130022510000000	Fahrbahnbelag	Base course
130011131310000	Fahrbahnplatte	Deck slab
130011131325000	Endquerträger	Support crossbeam
130011131324000	Querträger	Support crossbeam
130011131323000	Längsträger	Girder
130021500000000	Lager	Steel bearings
130011914000000	Flügelmauer	Wing wall
130011911000000	Widerlagerwand	Abutment wall
130021211000000	Streifenfundament	Strip footing

Figure 22. Dissasembled bridge model with its elements associated with the corresponding objects from the ASB-ING catalogue

4.2.1 Update I: Visual Bridge Inspection and Sensor Monitoring

Update I includes the update of the results from the visual bridge inspection. Additionally, it is shown how data from a sensor can be selected within the model.

Requirements

In order to link the results of a visual inspection with the IFC model, requires an existing IFC model of the asset and condition data that have the same referencing. In the present case, this is ensured via coordinates of the observed damage and the sensor (see chapter 3.1.4).

Results

Figure 23 shows the representation of damage (or any other finding) from an inspection. The component under consideration is a girder for which an inspection result is available. By clicking on the marked point on the element, a window opens that contains the essential information on this inspection result. This includes the construction type of the element, the extent of the damage and the condition rating. The attributes observation type and observation photo are contained under observation information.

Figure 23. Screenshot from Visual Bridge Inspection

The second application example involves the representation of a sensor mounted on the girder of the bridge. These are strain gauges that continuously record measured values and are saved in an export file (see Figure 24).

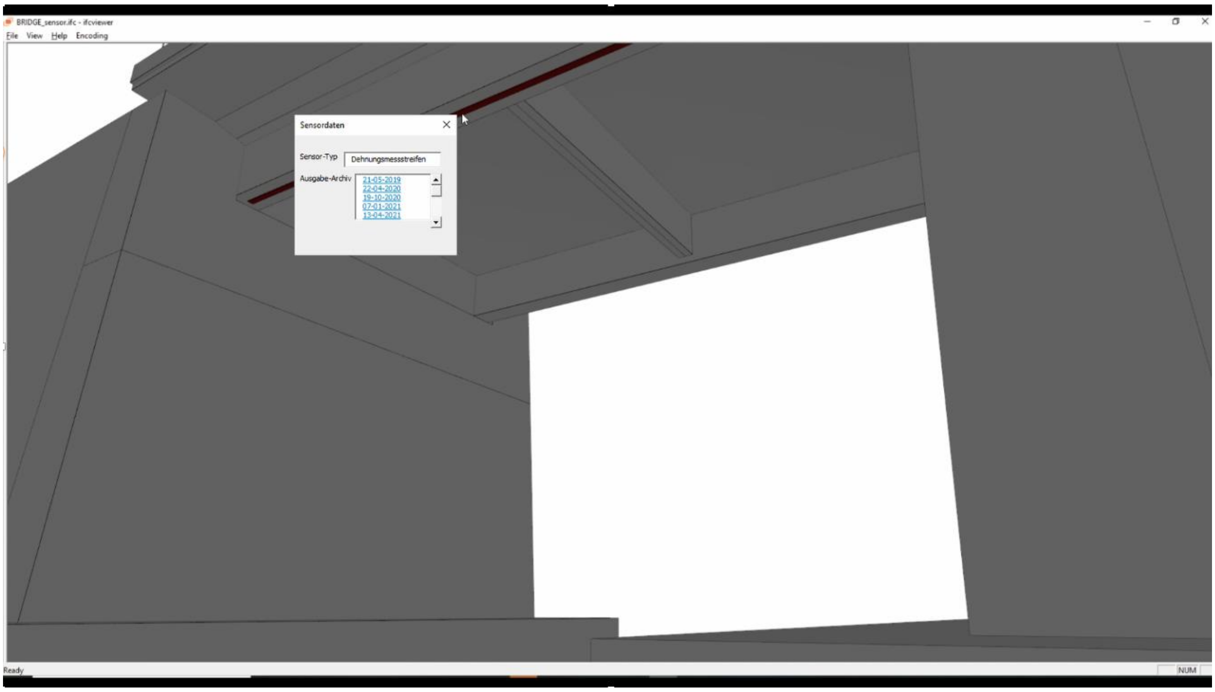


Figure 24. Screenshot Sensor monitoring

4.2.2 Update II: Bridge Maintenance Planning

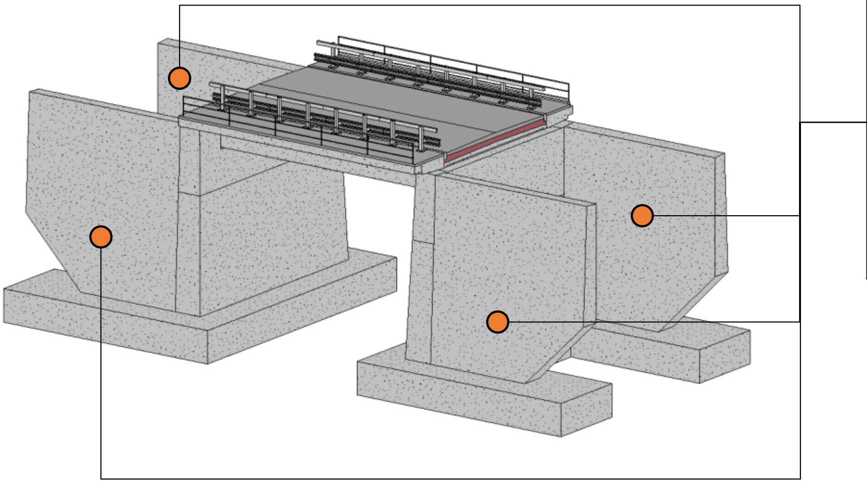
Requirements

To link the results of the maintenance planning with the IFC model, an existing IFC model and data of planned interventions that have the same referencing are required. Therefore, it is required that the planned maintenance interventions are assigned to the specific elements of the structure according to the NRA's ontology.

Results

Each element of the structure has assigned information on its planned maintenance interventions in the next years to come. The planned interventions of various elements can be queried directly via this layer.

By clicking on an element, the planned maintenance interventions are displayed to the user. This includes information on the type of intervention, the planned time of this intervention and the costs estimate. Figure 25 shows an example of a planned maintenance intervention in the year 2024. It is planned to apply a coating renewal on all four wing walls. The estimated costs for this treatment amount to 12,400 €.



Attribute	Value
ID ASB-ING	130011914000000
Bezeichnung	Flügelmauer
Designation	Wing wall
Type of intervention	Coating renewal
Planned time [year]	2024
Costs per Unit [EUR/m²]	15
Total costs [EUR]	12 400

Figure 25. Planned intervention treatment for wing walls in 2024

4.2.3 Update III: Updating the as-built model

Requirements

After the construction phase, the current information on the geometry of the structure as well as on the achieved installation quality must be linked to the 3D model. For this purpose, the construction material data, for example, must be assigned to the individual geometric elements of the structure.

Results

Figure 26 shows an example of the properties of the retaining and wing walls. The designation of the component according to ASB-Ing, the date of installation, the selected design, the material used for the masonry and the maximum joint width can be called up.

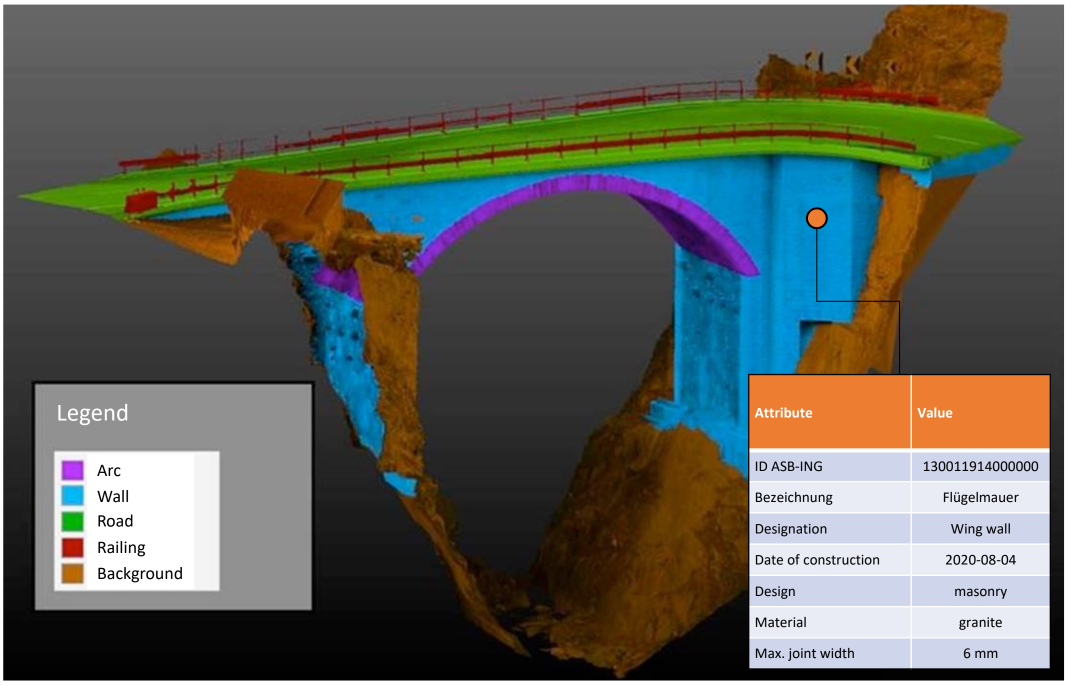


Figure 26. Screenshot from an as-built model of an arch bridge in Kanton URI (Switzerland)

4.3 Use Case 2: Roads

4.3.1 Update I: Road Condition Survey

Update I includes the updating of the results from the inspection or condition survey and assessment.

Requirements

To link the results of the condition survey and assessment with the IFC model, it requires an existing IFC model and condition data that have the same referencing. In our case, this is ensured via the distance to the previous node, with the method from nods-reference to alignment. This links and projects the condition data onto the IFC model.

Results

The virtual layer is filled with the linked results from the condition survey and assessment. The condition of various sections can be queried directly via this layer. By clicking on a section, the surveyed data and its assessment are displayed to the user. From this, the user can now determine contexts where a critical condition prevails. In addition to the condition data, all relevant data such as material properties and the road structure are displayed.

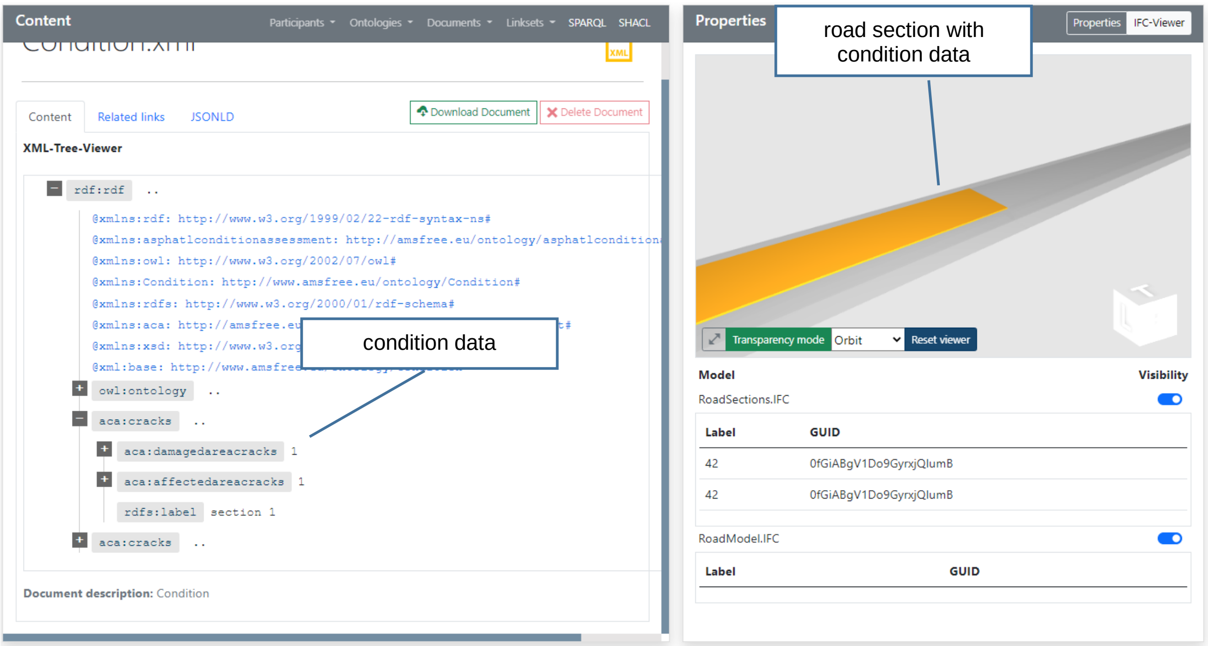


Figure 27 Screenshot from ICDD platform: road section of as-built model with condition data

4.3.2 Update II: Road Maintenance Planning

Update II includes the update of the maintenance planning with prioritised maintenance interventions.

Requirements

In order to determine the need for maintenance interventions, the results of the condition survey and assessment are queried and output via a SPARQL query. The data can now be used outside the model. In addition to the need for maintenance interventions, economic considerations and optimisations must then be applied. Thus, maintenance planning can be completed. The complete maintenance planning can now be linked to the model. Therefore, it is again necessary to apply the same reference to map the conservation planning onto the model.

Results

After a successful Update II, the maintenance planning and the model are linked to each other in Figure 28. This allows the planned intervention and its timeframe to be identified for each asset. These can be queried and displayed as all other Information via SPARQL in tables and in the IFC viewer. Also, bundles of interventions, which contain a number of assets, can be combined. These can be exported together for the program planning and processed correspondingly.

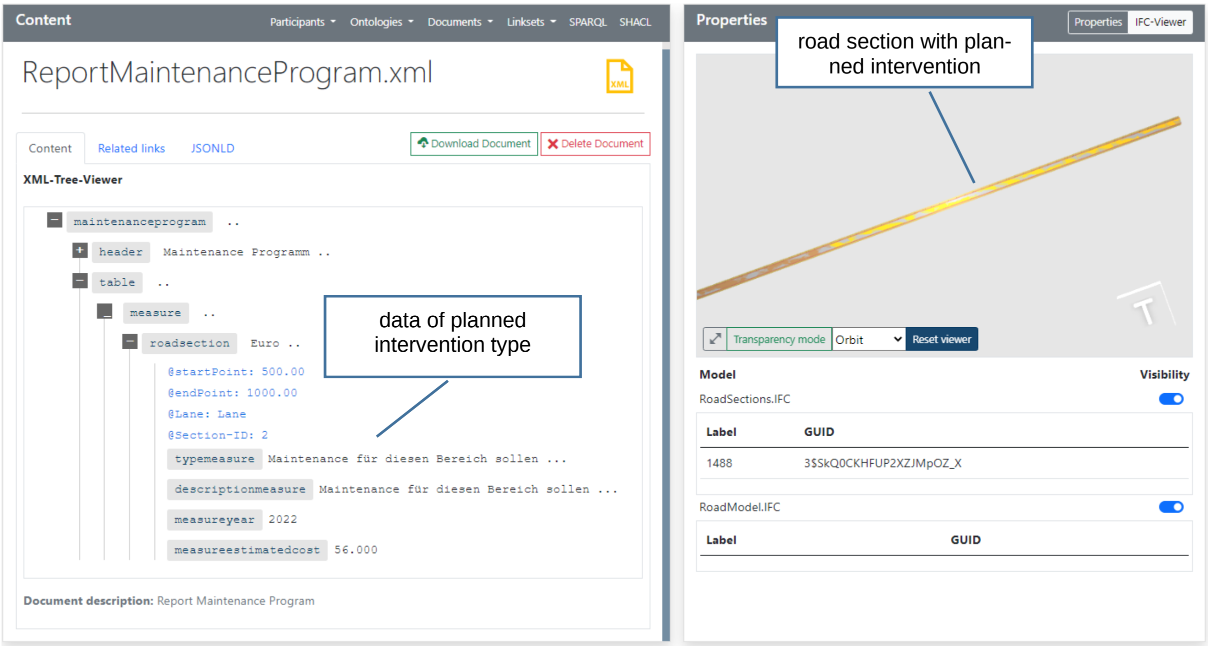


Figure 28 Screenshot from ICDD platform: as-built model with road maintenance planning

4.3.3 Update III: Updating the as-built model

Update III includes the update of the "as-built" model after construction phase.

Requirements

The detailed planning of interventions also takes place external to the model. Based on the export of the identified road sections with planned intervention, a detailed engineering and construction planning is conducted. This external process creates the planning model for tendering, contracting and construction. The maintenance intervention is executed based on the construction model. During the construction work and at the end, the as-built model is created and adapted by the contractors, which is uploaded back to the platform (see Figure 29, IFC-viewer). Therefore, it is necessary to be able to reference the as-built model of layers or complete road sections from construction phase onto the right road sections to the existing model in the ICDD platform.

Results

The next step is to replace the former as-built model with the new one. Therefore, new and modified sections are identified. Then, the sections of the old model that overlap with the changed sections are removed from the model and replaced with the new sections of the as-built model. However, the old sections receive a replacement date and are archived in order not to lose the information. This creates an up-to-date database that combines the information on existing sections and newly built sections. This becomes the current as-built model for further modifications.

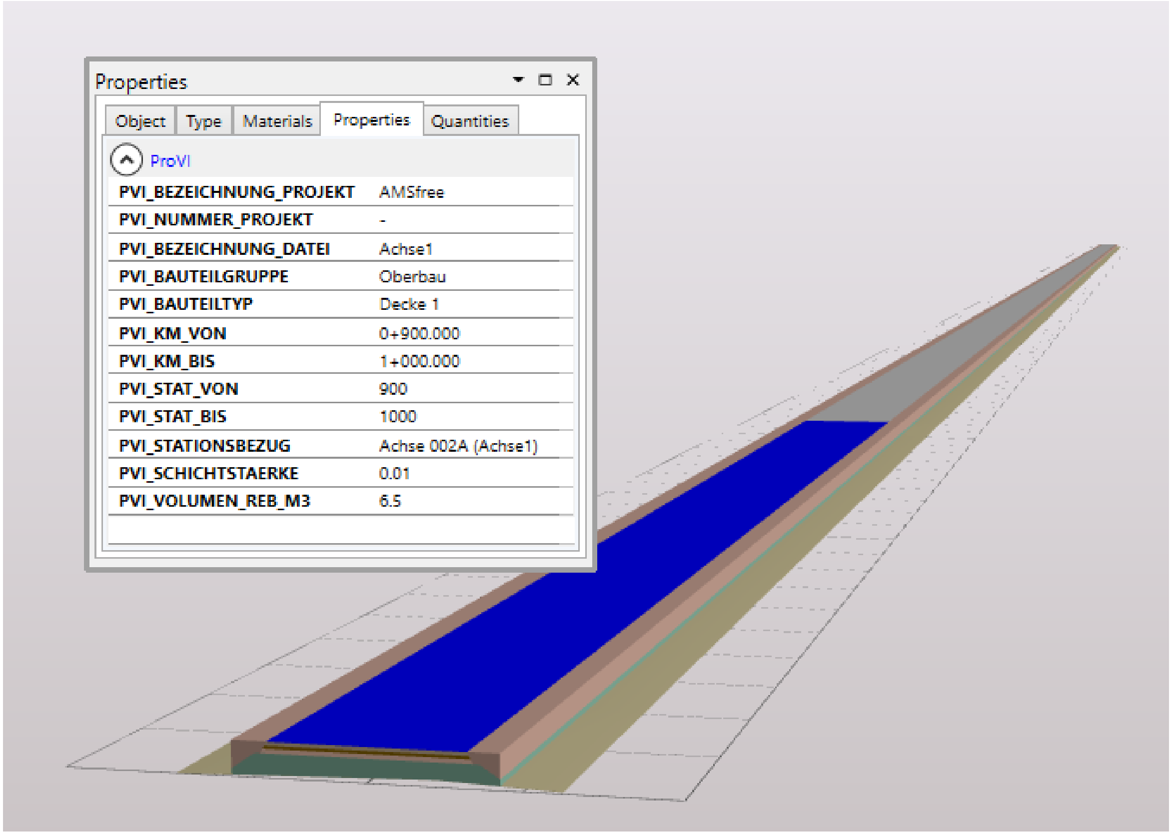


Figure 29 Screenshot from updated as-built model (IFC-viewer)

4.4 D6.1 Guideline IFC Property Mapping

Since the IFC schema version 4 has been released, the customized properties can be generated within extensible property sets as the *IfcPorpertySetsTemplate.* The definition of each property uses the *IfcPropertyTemplate,* which must then be assigned to the related *IfcPropertySetsTemplate* using HasPropertyTemplates*.* As mentioned in deliverable 3.2, the defined property set template can then be declared as *IfcPropertySet* with the relation *IfcRelDefinesByTemplate* and applying it to a concrete *IfcObject*. This property set can generally be related to an *IfcObject* using *IfcRelDefinesByProperties.* The described process of defining property set template, and relation of the IFC entities by using the customized properties are shown in the Figure 30 by buildingSMART.

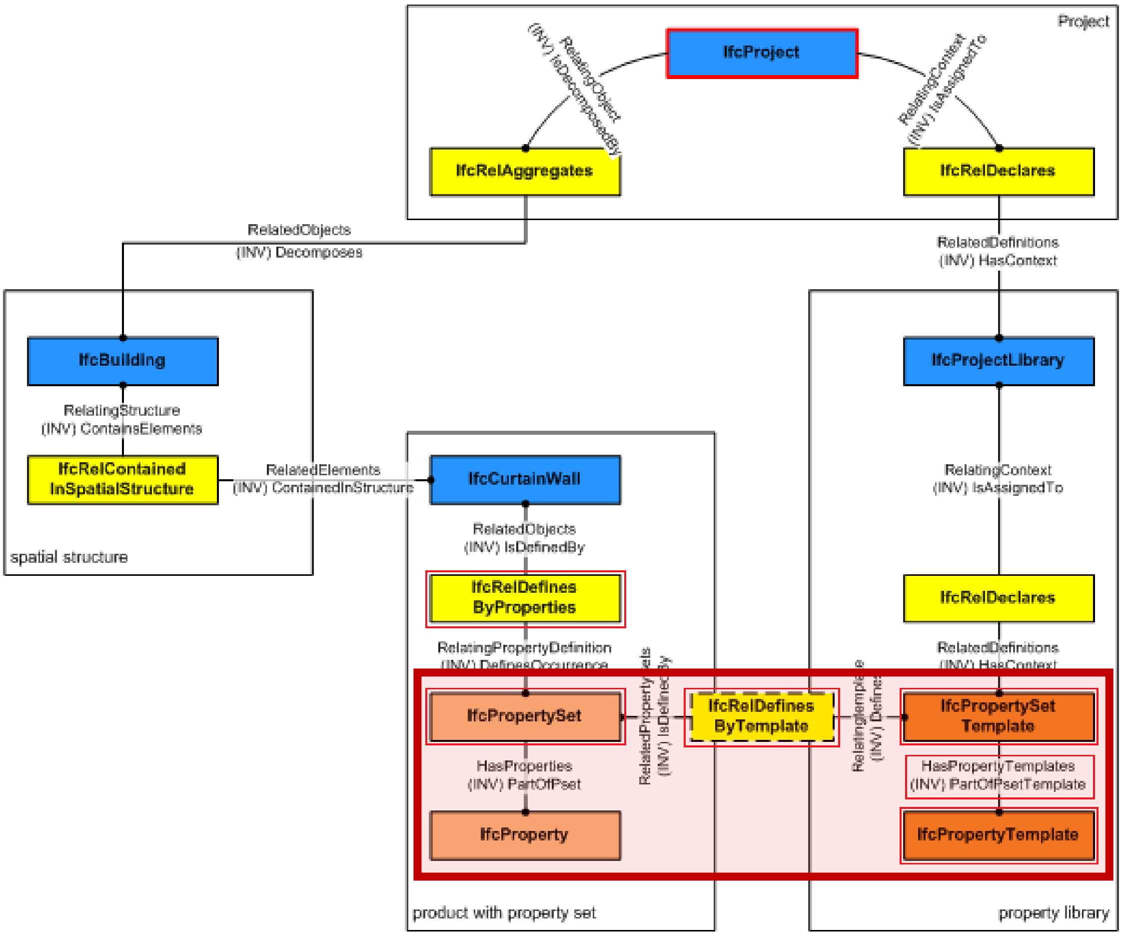


Figure 30. Property set template relationships (by buildingSMART, IFC-Schema, Version 4_3, RC2)

In accordance with the schema definition, common BIM design applications allow the user to upload their own property sets and assign these to the required building elements. As a preliminary, the user should define the properties contained in the property set template with Name, Property Type, and Data Type. For instance, several property sets for asphalt performance and asphalt condition assessment are described in deliverable 4.2. These property sets can then be assigned for sections defined as IFC entities or of a pavement object model.

4.5 D6.2 IFC Property Mapping Examples

4.5.1 Bridge IFC Model

The model used as an example is a BIM of a 12.5 meter span simply supported double girder bridge built in the 1930s. The bridge was modelled using Autodesk Revit. The model complies with LOD 350. Girders, railings, roadsides, and asphalt cover are modelled as in-place structural framing components. Finally, the model was exported in IFC format. Figure 31 shows the modelled IFC model of the bridge.

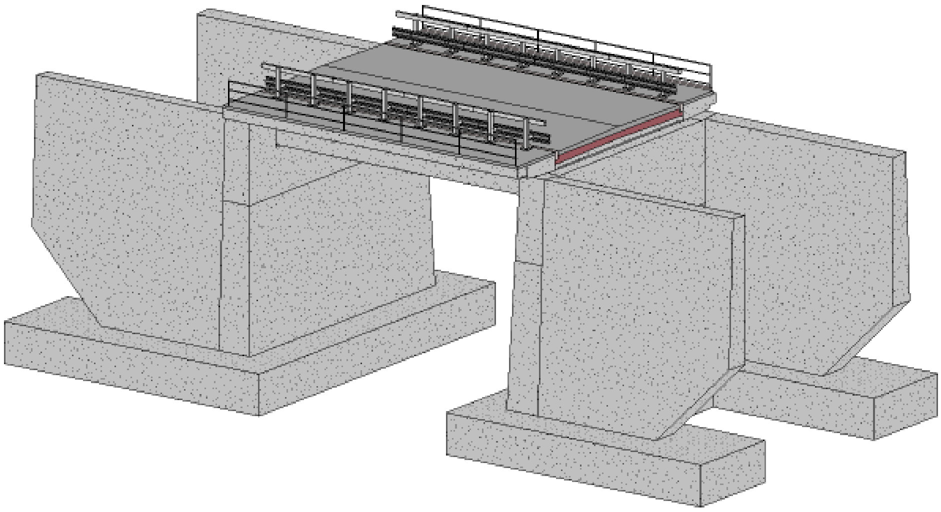


Figure 31. Exemplary BIM model of a bridge (Isailović 2020)

4.5.2 Road IFC Model

The IFC example model of the road is a very simple model of a 1 km long straight road section. This is split into two 500 m long construction sections. Furthermore, the section is divided into ten 100 m condition sections. The model consists of pavement surface layer, asphalt binder course, asphalt base layer and the unbound base layer. In addition, the model has a virtual layer to store conditions and measures on the corresponding sections. The model was created with the AutoCAD extension ProVI and exported to IFC format.

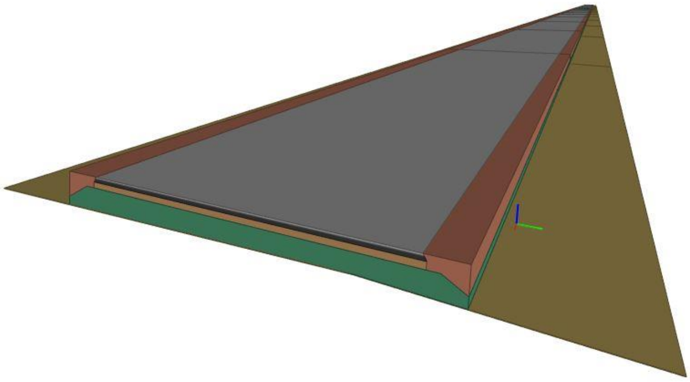


Figure 32. Exemplary BIM model of a road section

4.5.3 Property extension

Since not all properties are available in the IFC, the properties must be extended in order to link further data with the model. Thus, extended property sets were defined for the condition information and these can be linked to the corresponding pavement segment and layers of a road model via an ontology authored for this purpose. The external file with the condition information is then only linked to the model and not directly integrated.

The extended property sets are defined and listed in Report 4.2. And available for download at http://data.amsfree.eu/

(Login: AMSFree, password: CEDRCall2018!).

4.6 D6.3 Mapping Software Architecture

For creation of customized property sets as templates and adding the defined property sets to the entities of an IFC model, a mapping tool was developed with consideration for the services shown in the software architecture in Figure 33.

The tool must contain three major components to realize the creation and mapping of properties within IFC schema:

- Templating: to generate the property set template
- 3D Viewer: to view the geometry and interact with IFC model
- Model Content: to view the structure and properties of the IFC model and select the IFC object.

In each component, the necessary functionalities are introduced as following:

Templating includes the three functions. The user can create a property set template with a human readable form provided by the user interface. The input data for the property set will be converted into IFC schema. The generated property set templates can be exported in xml or other common data types for further use in model design and view applications. With the existing property set templates, the data of the properties can be added to the IFC model object. In the same way, the user can import the property set template in the supported data type and add them to the IFC model in this tool. To attach the properties to an IFC model, the tool must enable the user to view and interact with the IFC model. The functions are realised through the components of “IFC Apstex Toolbox Framework”.

3D Viewer and **Model Content** are components performed based on IFC visualisation tool. There are various visualisation tools, e.g. Xbim-Toolkit (https://docs.xbim.net/) which enables an integration of the 3D viewer into a self-developed system. In the introduced system, we prefer to use the IFC Apstex Toolbox Framework. In **3D Viewer**, the core function is the visualization of geometry and the interaction with the 3D object. The structure and the semantic data of the IFC model, such as properties, can be listed in the user interface by functions of **Model Content**. The filtering of IFC objects can be realised by selecting IFC Entities using a structure list.

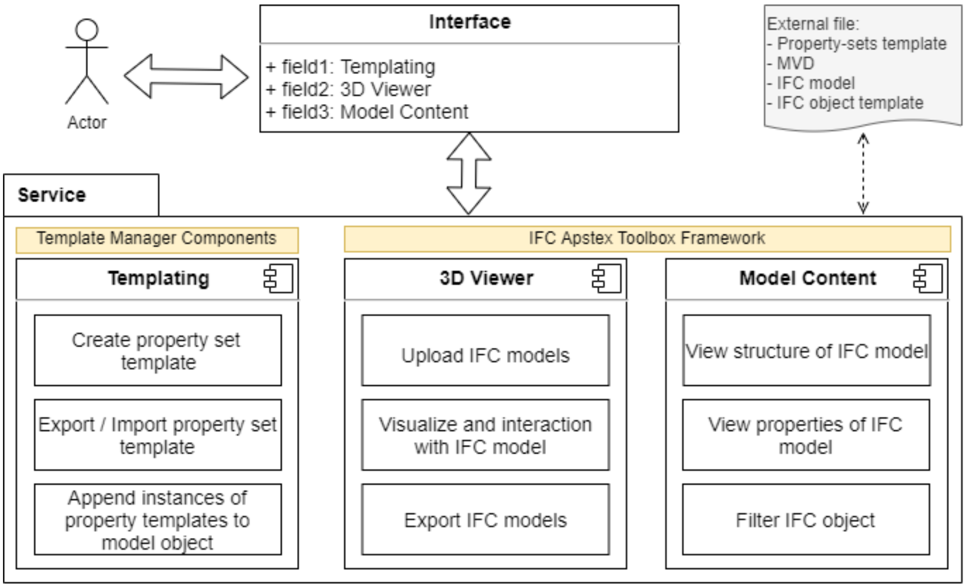


Figure 33. System Architecture of a Mapping Tool for the IFC Property Template

5 References

CEDR, 2017: Technical Report 2017/06. TG Asset Management final report 2017. CEDR's Secretariat General. ISBN: 979-10-93321-32-5.

FGSV, 2019: Directives for the Calculational Dimensioning of Traffic Infrastructures with Asphalt Wearing Courses (RDO Asphalt)

Hagedorn, P. (2018). Implementation of a Validation framework for the information container for data drop. In M. Steiner, M. Theiler, & M. Mirboland (Hrsg.), 30. Forum Bauinformatik (publishers_version, S. 147–154). Forum

Isailović, D. (2020): Digital Representation of as-damaged reinforced concrete bridges, Doctoral Dissertation, University of Belgrade, Belgrade, Serbia

Isailović, D., Hajdin, R. (in preparation): Geometry as a common ground for BMS and BIM. IABSE Symposium Prague 2022 – Challenges for Existing and Oncoming Structures, Prague, Czech Republic

ISO 19650-1:2018 (2018): Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) – Information management using building information modelling – Part 1: Concepts and principles

ISO 16739-1:2018 (2018): Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries — Part 1: Data schema

ISO 16739:2005 (2005): Industry Foundation Classes, Release 2x, Platform Specification (IFC2x Platform)

ISO 16739:2013 (2013): Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries

ISO 21597-1:2020 (2020): Information container for linked document delivery — Exchange specification — Part 1: Container

ISO 55000: 2014 (2014): Asset management — Overview, principles and terminology

O'Keeffe, A., Weise, M., van Lanen, R., Hoel, J. E., & Stolk, S. (2018). INTERLINK D8 - WPD3 Report. CEDR.

PIARC (2017): PIARC Asset Management Manual – A Guide for Practitioners. https://road-asset.piarc.org/en

Stöckner, M., Hajdin, R., König, M., Gavin, K., Liu, L., Zwernemann, P., Blumenfeld, T., Schiffmann, F. (2021). AMSfree report D 3.1 "Current assessment techniques". CEDR-project AMSfree

Stöckner, M., Hajdin, R., König, M., Gavin, K., Liu, L., Zwernemann, P., Blumenfeld, T., Schiffmann, F. (2021). AMSfree report D 3.2 "Information Delivery Manual (IDM) for condition Assessment". CEDR-project AMSfree

Stöckner, M., Hajdin, R., König, M., Gavin, K., Liu, L., Zwernemann, P., Blumenfeld, T., Schiffmann, F. (2021). AMSfree report D 4.1 "Definition of an Asset Management reference process". CEDR-project AMSfree

Stöckner, M., Hajdin, R., König, M., Gavin, K., Liu, L., Zwernemann, P., Blumenfeld, T., Schiffmann, F. (2021). AMSfree report D 4.2/4.3 "Information Container for Road Maintenance Planning and Bridge Condition Assessment". CEDR-project AMSfree

Stöckner, M., Hajdin, R., König, M., Gavin, K., Liu, L., Zwernemann, P., Blumenfeld, T., Schiffmann, F. (2021). AMSfree report D 5.1 “IAMS-oriented Information Delivery Manual”. CEDR-project AMSfree

Stöckner, M., Hajdin, R., König, M., Gavin, K., Liu, L., Zwernemann, P., Blumenfeld, T., Schiffmann, F. (2021). AMSfree report D 5.2 “IAMS-oriented Application and Extension of the IFC Standard”. CEDR-project AMSfree

Stöckner, M., Hajdin, R., König, M., Gavin, K., Liu, L., Zwernemann, P., Blumenfeld, T., Schiffmann, F. (2021). AMSfree report D5.3 “Linking Guide of European Road OTL and National Classifications”. CEDR-project AMSfree