Conférence Européenne des Directeurs des Routes

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AMSFree

CEDR TRANSNATIONAL ROAD RESEARCH PROGRAMME

D3.2 Information Delivery Manual (IDM) for condition assessment

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1 Introduction

To implement seamless information exchange, the data transfer points and associated processes must be described in detail. Thus, there must be a common understanding of all processes throughout the life-time of an infrastructure asset, including the information required for and the results of each process. The international standard ISO 29481-1/2 (building information modelling - Information Delivery Manual = IDM) is usually used to analyse and specify the information exchange in the context of building information modelling. This standard specifies how the processes are carried out and how the information required for their execution and results are identified and described. The first step in developing an IDM is to consider the type and context of information exchange. The content of a specific IDM defines the need for information exchange, names the actors and specifies the information. In this report, the focus is on the processes performed for the condition assessment of bridges and roads. Each IDM must begin with a short, clear description of the content, use case, objective and scope that the component is intended to cover, or an indication of the subject or operational requirement on which the information must be exchanged. In a final step, the content is then transferred to a specific data model, which will be developed in the context of this project within the work package 4.

2 Condition Assessment

As part of the analysis, the existing processes and also new technical possibilities for condition assessment of roads and bridges were considered. Depending on the type of infrastructure and the acquisition method, different data is stored and afterwards exchanged. In the following, the essential points for the condition assessment are summarized once again. On the basis of this assumption the development of a process map is carried out.

2.1 Bridges

The objects to be controlled depend on the type of infrastructure and the goals of the assessment. The condition assessment of bridges is usually based on the inspection of individual components. This inspection also includes functional parts (e.g. bearings, joints, and transition slans) as well as anchorages of components (e.g. contact protection, noise barriers, and pipes) see figure 1. Usually there is a list of bridge elements which have to be inspected regularly.

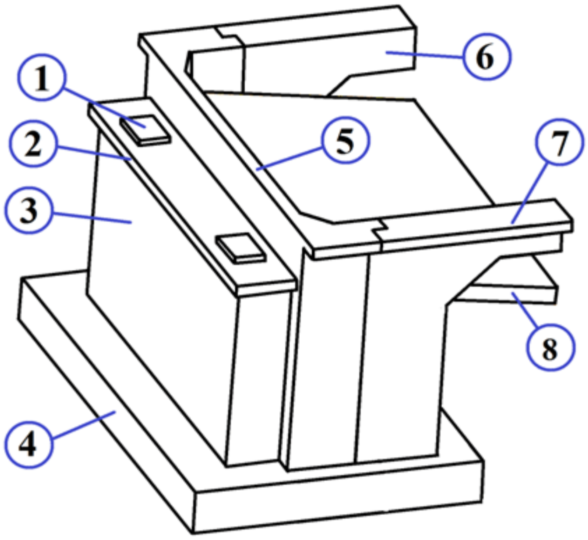

Figure 1 Typical elements of a bridge abutment (according to Kowal & Śledziewski, 2017)

In a first step, the condition of each element is assessed and then an overall assessment can be performed with regard to structural safety, traffic safety and durability. This approach is used e.g. in Germany to assess the condition of bridges.

Structural safety: The stability characterizes the property of a structure or individual parts of a structure to be able to withstand the critical combination of actions (reduced accordingly in the case of restrictions on use) without damage.

Traffic safety: Traffic safety is a measure of the structure's design in accordance with the recognized rules of technology at the time of testing, which includes the requirements for safety and order with regard to the safe and proper use of the structure. It thus includes safety for road users and vehicles as well as safety for persons and property in the vicinity of the structure. It is assumed that the road users exercise reasonable caution, taking into account the external circumstances, and exercise the care customary in traffic.

Durability: Durability characterizes the ability of a structure or individual parts of the structure to meet structural and traffic safety criteria for intended purpose while performing regular maintenance over the full extent of designed service life.
In particular, the following observations must be documented,

- unusual changes to the structure,
- considerable deficiencies/damage to and absence of traffic signs, safety devices and fall protection devices,
- considerable deficiencies/damage and contamination of drainage systems and transition structures,
- considerable deficiencies/damage to overlay,
- considerable impact damage and concrete spalling, noticeable cracks,
- apparent deformations and displacements of the structure,
- defects/damage to slopes,
- scouring and landings in waters.

The results of the inspection of the structure including all observations, measured data, the results of the additional examinations, sketches and photos need to be compiled and documented in a report. The inspection is generally conducted by independent organizational units. This ensures a more objective assessment. Some of the proven classical methods for inspection of bridges include

- tapping of concrete surfaces to detect cavities and delamination,
- measurement of cracks and comparison of the results with previous measurements,
- checking the tightness of fasteners (screws, bolts),
- measurement of deformations (e.g. deflection) for possible conclusions about loss of load-bearing capacity,
- measurement of displacements and gap openings on bearings to detect unplanned movements,
- chemical tests (measuring the carbonation depth, determining the chloride ion concentration) on concrete parts, to estimate the corrosion risk for the reinforcement,
- testing the concrete strength by means of a sclerometer or by core removal and subsequent laboratory examination.

Increasingly, other non-destructive testing methods are also gaining in importance. Usually these methods are used in the context of an in-depth investigation. Non-destructive testing methods include, for example,

- electrochemical potential measurements to determine active chloride-induced, reinforcement corrosion in reinforced concrete structures,
- ultrasonic echo and impact-echo methods for detecting voids in concrete, for determining reinforcement debonding or for locating non-compressed areas in the duct of post-tensioning system,
- infrared thermography for locating moisture damage, e.g. in delamination zones,
- radar measurements and laser measurements for the large-scale preliminary investigation of structures.
- image analysis as means to detect damages
- Interpretation of Space-borne Synthetic Aperture Radar Interferometry (InSAR) collected from satellites to monitor relative deformations

2.2 Roads

Roads must be safe to drive on, withstand actions, offer a certain level of driving comfort, develop as little rolling noise as possible and, of course, last for a long time. In order to detect initial damages or faults at an early stage and to comply with road safety regulations, they are regularly checked by experts from the freeway and road maintenance authorities. Maintenance management based on objective and up-to-date data and taking into account all relevant influence factors is indispensable when it comes to

- ensuring the safe travel over a designed service life,
- recording and incorporating changes in traffic volume and composition in a timely manner,
- minimizing traffic disruptions caused by construction and maintenance work, and
- achieving an optimal cost/benefit ratio.

Today, existing measuring and acquisition methods make it possible to objectively record the condition on the road surface (or texture). The transverse and longitudinal evenness are measured, for example, with vehicles using laser technology. The friction is determined with the measuring method of the inclined measuring wheel. The road texture is captured and recorded with area or line scan cameras. The concept of condition assessment of the surface is based on the acquisition and evaluation of images of the pavement by registering the presence of certain features (or defects) defined in given damage catalogue. In the first step, each image of a road surface is divided into smaller segments. Afterwards, each segment is examined to determine whether it is affected by one or more of the damage characteristics. The recognition of the damage characteristics is carried out by trained personnel, who evaluate the images with the help of acquisition software and mark the segments affected by damage characteristics and, if necessary, attribute them with further information.

2.3 Document types of condition information

The data of the condition assessment of bridges and roads differ fundamentally in content. However, if only the document types are considered, a generalization can be made. Generally, the following document types can be distinguished for both types of infrastructure:

- Images (pixel-based documents),
- Laser scans (point-based documents),
- Measurement series (structured documents),
- Forms (structured documents) and
- Textual descriptions (unstructured documents).

All documents should be described using some kind of metadata. Metadata is data that provides information about other data. Metadata can provide information about one or more aspects of the data. For example, it is used to summarize basic information about data which facilitates tracking and working with them. Metadata is therefore a mandatory prerequisite for processing the listed documents. In addition, a data model must be specified for structured documents so that they can be interpreted by a person or a system. When describing data exchange using the IDM method, metadata documents must therefore also be considered in addition to the BIM models. In each case, it must be determined whether certain information is to be transferred to the BIM model or whether it is only linked to the BIM model.

2.4 Localization of condition information

The location of a particular piece of information for the condition assessment is done differently for roads and bridges. However, a generalization can be made for the localization. In principle, information can be linked as

- Point-oriented,
- Area-oriented,
- Volume-oriented or
- Component-oriented.

Clearly, combinations are also possible. For example, a surface area for a certain component can be specified. The location of a particular piece of information can be specified absolutely or relatively. A component-oriented reference is often used for the condition assessment of bridges. The acquisition of the road condition is mainly done per segment (area). Therefore, it is necessary to divide roads according to the section to be assessed.

3 Information Delivery Manual for Condition Assessment

A major challenge when setting up a process map in the context of data exchange processes is to determine the level of detail. In this report, the Information Delivery Manual does not describe the processes of the contractors appointed to perform condition assessment and condition evaluation in detail. Rather, it focuses on the exchange of the results of the condition assessment and condition evaluation between the road operators and the inspecting organization. Of course, the implementation of a condition assessment can also be done by an internal staff member. However, there are always two different roles with different areas of responsibility.

It should be specified which information is to be handed over to the inspector and how the results will be returned. Subsequently, it should be possible to import the results into traditional as well as BIM-extended asset management systems. A generic process map can be created to describe this purpose of data exchange. Specialization and detailing are then carried out for the information to be exchanged at the two main data exchange points. The first data exchange point describes the transfer of information required to perform inspections assignment from the road operator to the inspector. The second data exchange point deals with the transfer of the results of the condition assessment to be integrated into the asset management systems. The import of the delivered information containers into existing asset management systems is considered in the following reports. The high-level process map for data exchange between the public operator of a built infrastructure and the persons carrying out a condition assessment is shown in Figure 2.

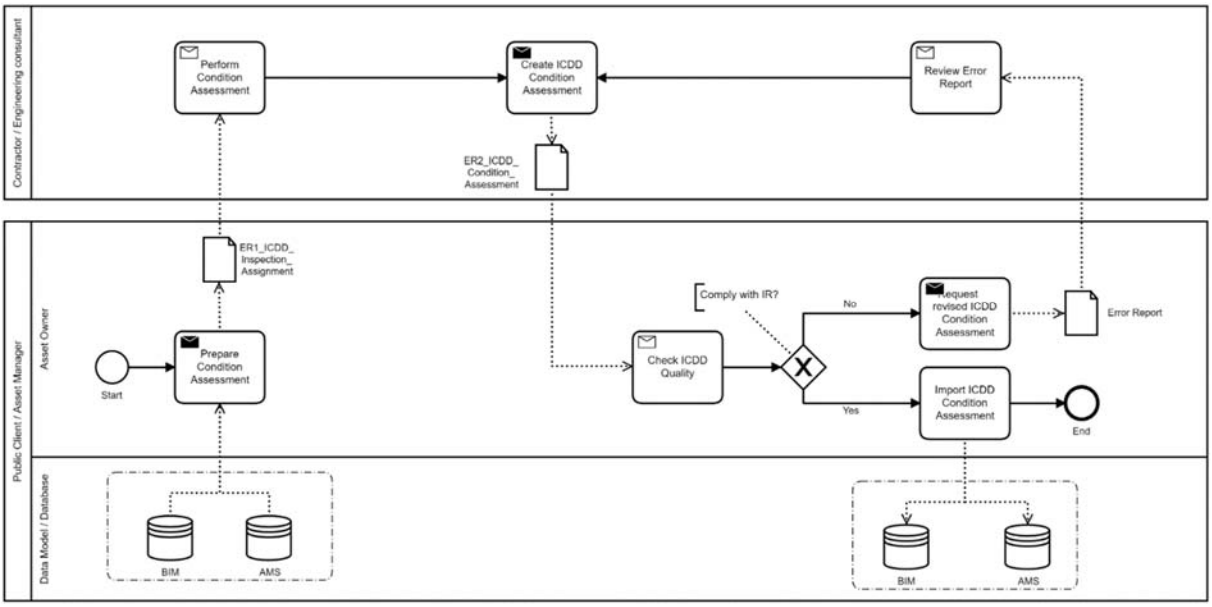

Figure 2 Generic process map for condition assessment

Process Model			
Name:	PM_Condition_Assessment		
Identifier:			
Autors:			
Create Date:			
Document Owner:			
Task	**Name**		**Description of Task**
	Prepare Condition Assessment		Asset Manager requests for an inspection and prepares the ICDD: - in according to the type of inspection - extracting parts of the IFC model - using a template for the report
	Perform Condition Assessment		The inspector receive the ICDD for condition assessment and performs the inspection - using certain technologies - compiling the results - creating a report
	Create ICDD Condition Assessment		The inspector stores the result of condition assessment in the ICDD: - in according to the data model "ER1_ICDD_Inspection_Assignment" - linking the different information - checking the results and fulfillment of the information requirements The result of condition assessment are delivered in the form of ICDD
	Check ICDD Quality		Asset Manager checks the ICDD against the exchange requirment - in according to the data model "ER1_ICDD_Inspection_Assignment" - creating a quality report
	Request upgrade of ICDD Condition Assessment		If the check result of delivered ICDD is not compliant with the exchange requirement, a error report be will created and sent back to the inspectior for a revision
	Review Error Report		Inspector checks the error report and revises the ICDD: - in according to the data model "ER1_ICDD_Inspection_Assignment" - linking the different information - checking the results and fulfillment of the information requirements The result of condition assessment are delivered in the form of ICDD
	Integrate ICDD Condition Assessment		If the delivered ICDD is compliant with the exchange requirement, the data will be saved back to the BIM/AMS.
Exchange Requirements	**Name**	**Type**	**Description of Dokumentation**
	ER1_ICDD_Inspection_Assignment	ICDD	Information Container for linked Document delivery with all necessary information for preparing the condition assessment. It should be specified for each typ of the condition assessment.
	ER2_ICDD_Condition_Assessment	ICDD	Information Container for linked Document deliverey with all necessary results of the condition assessment
Object Data	**Name**	**Type**	**Description of Object Data**
	BIM	ifc	An as-built model using IFC
	AMS	-	Asset management system for storing the condition assessement results

Figure 3 The description of generic process map for condition assessment

It is assumed that information about the infrastructure, including the data collected and condition assessments made so far, is available through an asset management system with a linked BIM environment. Detailed specifications regarding the architecture of this heterogeneous data source will be provided later in the course of the definition and implementation of this process (WP4). When a new condition assessment for a road or bridge is planned, all relevant information is compiled by the asset manager. The information is exported from the linked data source using specific queries. The detailed structure of this information will be explained in the following chapters depending on the type of the infrastructure object and the information to be documented. It is assumed that information from the BIM model as well as linked information on the current condition (e.g. images, evaluations, etc.) is transferred to the inspecting organization. Furthermore, the inspection assignment itself must also be described digitally, i.e. it must be marked in the BIM model which geometric areas or objects require inspection. Furthermore, a specification must be defined to decide which information is to be acquired and linked to the existing models. A formal and digitally verifiable information requirements are provided for this purpose. The individual processes and data objects are described below in more detail.

Prepare Condition Assessment

In this process, the information necessary for the condition assessment is compiled. In the BIM model, the corresponding areas or objects are selected. It may also be necessary to create new sections for which a condition assessment is to be performed. This is typical for the condition assessment of roads. Furthermore, it is specified which characteristics are to be captured. For example, a condition assessment of road surfaces can be done by means of images. For this purpose, a template is defined how the raw data and results are linked to the BIM model. As a result, provided and requested information is transferred to the assigned persons in the form of an Information Container for linked Document Delivery (ICDD Inspection Assignment).

Perform Condition Assessment

Based on the assignment, the actual damage detection and condition assessment is carried out. Different technologies are used for this purpose. The internal processes of inspecting organization will not be considered further. It is assumed that the procedures are known and the condition assessment is carried out by trained personnel.

Create ICDD Condition Assessment

In this process, the captured and interpreted data is prepared on the basis of the information requirements. The provided templates are used to document the information. Furthermore, various links were specified, which now have to be implemented with the individual data. For example, a template for the structure of a damage report for a bridge component was specified. This damage report has to be filled out and additional documents such as pictures have to be linked to the report as well as to the bridge element. The instructions for positioning and referencing must be considered as well. The result is a completed information container (ICDD Condition Assessment), which meets the previously defined information requirements.

Check ICDD Quality

The information container can contain a huge amount of information that should be validated in detail. The validation includes a formal and technical examination. The technical validation requires comprehensive experience and can be supported by suitable visual representations. The formal validation includes the compliance with the information requirements. The primary aim of the formal validation in this context is to check that the link types defined in the container conform to the link types specified in this document. The validations may be done using the SHApe Constraint Language (SHACL), a W3C standard for validating RDF graphs against constraints. If errors or problems are detected, a revision or correction must be made. The corresponding errors are sent as a report to the responsible persons, who can then make an adjustment.

Import ICDD Condition Assessment

In the final step, the valid condition assessments, including the underlying data, are then integrated back into the asset management systems and linked BIM data environments. Appropriate import functionalities must be provided for this purpose.

3.1 Use Cases of Condition Assessment

As already explained, condition assessment and condition evaluation depend on the type of infrastructure and the assessment technology. Within this report three different technologies are considered:

- visual inspection for bridges,
- dynamic response analysis for bridges and
- ground penetrating radar for roads.

For these three use cases, specific information containers must be defined to support the general process map. The information containers differ fundamentally according to the ontologies, links and documents that are used and stored. Before the individual information containers are defined, a short outlook on existing ontologies for the description of damages for bridges will be given.

3.2 Damage Ontologies for Bridges

In Hamdan et al. (2019) a core ontology for the description of damages is presented. In this work, a damage is differentiated into three levels of detail. A damage element corresponds to a single separable damage with exactly known dimensions, e.g. a crack in concrete with recorded width, length, depth and course. Several adjacent damage elements of the same type can be combined to form a damage pattern. These can be located in a damage area. The detailed description of elements and patterns can be omitted and instead areas with certain damages can be defined directly in a lower level of detail. For example, an area with several cracks with each crack width less than 0.2 mm or an area with moisture penetration of the masonry can be defined. In the case of bridge testing, the report usually suffices to define the degree of detail of the damage area with indication of rough dimensions or spans in which the damage is located. Furthermore, the ontology can be used to assign a description, a reason, other documents and an inspection date to a damage.

An extension to the core ontology already exists. Concrete Damage Ontology (CDO), consisting of classes for different types of damage and data type properties for the specification of exact numerical values for the extent of damage. The core damage ontology with its extensions is shown in Figure 4.

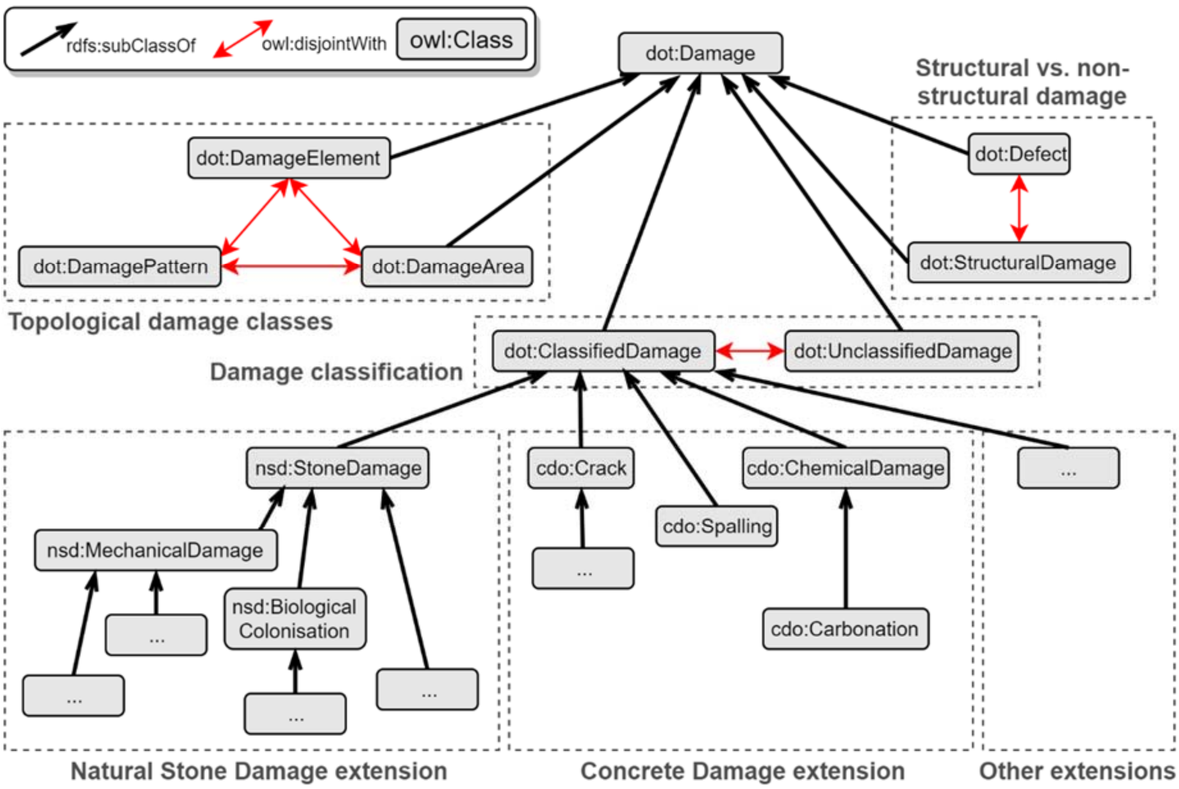

Figure 4 Components of the Damage Topology Ontology (https://alhakam.github.io/dot/)

Within the framework of the INTERLINK project, some test ontologies for structural assessment were developed for the German standard DIN 1076. The ontology asb-ing-classification describes all main construction and structural parts according to the key tables of ASB-ING. In addition, the ontology asb-ing-condition contains some information for the damage assessment. Unfortunately, the ontologies have not been evaluated in detail. Furthermore, the structure of the ontology for damage assessment is rather unstructured. However, this ontology is a good first starting point for further development.

3.3 Information Containers for Linked Document Delivery

The Information Container for linked Document Delivery (ICDD, ISO 21597) has been developed in response to a need within the construction industry to be able to handle multiple interrelated documents as a single information delivery. The ICDD is a specification for a generic container format that stores documents using various formats and structures, along with a means of linking otherwise disconnected data within those documents (including individual parts). These documents can have any syntax and semantics. An ICDD consists of four components (see Figure 5):

- An *index.rdf* file describes the container and its contents, including the documents contained in the container.
- An ontology resources folder is used to store the ontology. To provide the object classes and properties used for specifying and linking the documents within the container, the *Linkset.rdf* and *Container.rdf* files should be included.
- A payload documents folder is used to store all the documents. In this folder it is allowed to have subfolders for storing further documents.
- A payload triples folder is used to store all links as one or more so-called *Linkset* files and may have sub-folders.

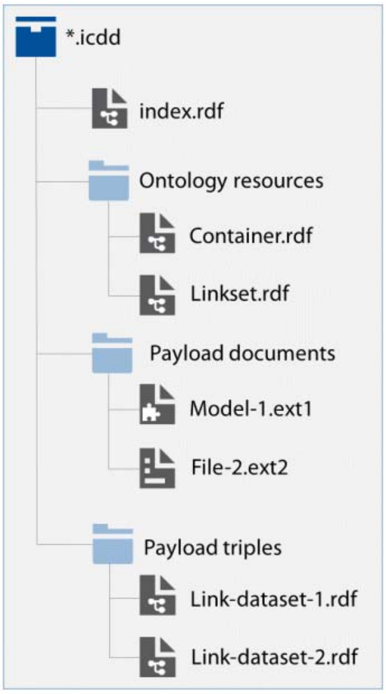

Figure 5 Components of an information container for linked data delivery in Hagedorn (2018)

Different relationships (or link types) can be used to add information about the contents of a container, rather than extending the contents. The defined link types provide the ability to express comparison, ordering and dependency relationships between the documents and entities within documents that form part of the payload of a container. The following link types can be used within an information container.

Grouping	Name	Description
Binary links that express comparative relationships	Identity	This link type relates two link elements that are identical but may be represented in different ways.
	Conflict	This link type relates two link elements that conflict with one another in some way.
	Alternative	This link type relates two link elements where one is an alternative to the other.
One-to-many links that express ordering relationships	Specialization	This link type relates one link element to one or more other link elements that are specializations or sub-classes.
	Aggregation	This link type relates one link element to one or more other link elements to form an assembly of parts where those parts exist independently.
	Membership	This link type relates one link element to one or more other link elements to form a grouping based on some consistent criteria.
One-to-many links that express dependency relationships	Replacement	This link type relates one link element to one or more other link elements where they are a development of or supersede it in some way.
	Elaboration	This link type relates one link element to one or more other link elements where they provide further explanation, reasoning, derivation, information or usage.
	Control	This link type relates one link element to one or more other link elements over which it exercises some type of control.

Figure 6 Link types specified in the ISO 21597 part 2

This contributes greatly to the value of the container by providing commentary, guidance and explanation of the relationships between link elements which could otherwise be unclear or ambiguous, without making any assumptions about, nor being dependent on the specific type of the link elements. This allows the container to be machine readable and human interpretable.

In the general the Process Map contains two essential data exchange points. For this purpose, the two exchange requirement models (ERM) are now defined. The first ERM is created and delivered by the road operator. This defines basic information about the order and the information request, how the inspection data is stored and linked to the building model. The second model is created by the contractor and delivered back to the client. It should contain all inspection results and the links to the BIM model.

3.3.1 Visual inspection of bridges

The visual inspection of a bridge is carried out for all important components. All damages should be documented both textually and visually. The documentation is based on a given template. A report should be created for each inspected component. The report is assigned to the component. If damages are present, the report is accompanied by a detailed description and corresponding photos. The corresponding structure of the two information containers is shown in Figure 7. The left table shows the documents of the Exchange Requirements (ER) model for inspection assignment, the right table shows the documents of the Exchange Requirements (ER) model for condition assessment.

Exchange Requirements Model		
Name:	Visual Bridge Inspection Assignment	
Identifier:	ER1_ICDD_Inspection_Assignment	
Description:	**Name**	**Type**
Index:		
	Index.rdf	rdf
Ontology Resources:		
	Container.rdf	rdf
	LinkSet.rdf	rdf
	DynamicSemantics.rdf	rdf
	DamageClassification.rdf	rdf
	ConditionClassification.rdf	rdf
	BridgeClassification.rdf	rdf
Payload Dcuments:		
	BridgeModel.ifc	ifc
	ReportTemplate.xsd	xsd
Payload triples:		
	RequestedReports.rdf	rdf

Exchange Requirements Model		
Name:	Visual Bridge Inspection Results	
Identifier:	ER2_ICDD_Condition_Assessement	
Description:	**Name**	**Type**
Index:		
	Index.rdf	rdf
Ontology Resources:		
	Container.rdf	rdf
	LinkSet.rdf	rdf
	DynamicSemantics.rdf	rdf
	DamageClassification.rdf	rdf
	ConditionClassification.rdf	rdf
	BridgeClassification.rdf	rdf
Payload Dcuments:		
	BridgeModel.ifc	ifc
	LocalPlacement.ifc	ifc
	Report.xml	xml
	ImageDamage.png	jpg/png/gif
Payload triples:		
	DamagePlacement.rdf	rdf
	ReportLinking.rdf	rdf
	ReportVisualDetails.rdf	rdf

Figure 7 Structure of information containers for the visual inspection of bridges

Ontology Resources

Container.rdf and *LinkSet.rdf* are the standard ontologies for defining the documents and links contained in the container. *DynamicSemantics.rdf* allows the user to insert and use a self-defined ontology within the container.

DamageClassification.rdf is an ontology for the description of damages. It should contain classes and properties, with which the general information of a structural damage, including size, description or inspection date, can be instantiated. For example, the Damage Topology Ontology and Concrete Damage Ontology can be used (according to Hamdan et al. (2019)).

ConditionClassification.rdf is an ontology to classify and evaluate the inspected component and any associated damage. Since the assessment of the condition of the structure is carried out according to national standards, the definition of this ontology should correspond to national regulations. For example, the "asb-ing-condition" from the INTERLINK project can be used for the German classification system according to DIN 1076 and ASB-ING.

BridgeClassification.rdf is an ontology to classify the individual components of a bridge. Since the classification of the bridge components is carried out according to national standards, the definition of this ontology should correspond to national regulations. For example, the "asb-ing-classiciation" from the INTERLINK project can be used for the German classification system according to ASB-ING.

Payload Documents

BridgeModel.ifc describes the as-built model of the bridge using the IFC format. However, this should only be an extract, i.e. only the most important components and information should be extracted from the complete as-built model. For this purpose, a corresponding Model View Definition (MVD) is usually created. All relevant geometrical and semantical information must be included that is required for the contracted inspection. However, the as-built model is not changed during the inspection. Additional information to be managed later in the BIM data environment can be added as external information. In particular, an additional document using the IFC format is added to localize information about the condition assessment.

LocalPlacement.ifc is an extension of the as-built model of the bridge (*BridgeModel.ifc*) to define areas for locating information for condition assessment. Both the geometric descriptions (e.g. points, areas, and volumes) as well as the semantic properties (as so-called property sets) can be added. It should be noted, however, that the document cannot be evaluated without the model of the bridge. Currently, there are very few software tools that allow the merging of two partial models based on the IFC format.

ReportTemplate.xsd defines a data schema for submitting the condition assessment in the form of a report using XML. This document can be understood as a kind of form to be filled in by the contractor. Mandatory fields and optional fields can be specified. In order for the reports to be evaluated automatically, specifications should be given as detailed as possible. The report template is usually based on national guidelines. The ontologies for the classification of components and damage are used within the report. The information requirements of the asset owner regarding the inspection result must be considered.

Report.xml contains the inspection result under consideration of the defined template. The amount of information must be sufficient to display a conventional (often paper-based) inspection report. This includes the metadata of the inspection, the evaluation of essential components, the damage assessment, etc. The report can be checked for completeness and formal correctness based on the given template. It is also possible that the information container contains several reports. However, the reports must also individually fulfil the defined scheme.

ImageDamage.png specifies an image to a recorded damage. For the images in the container different data formats such as png, jpg, or gif can be allowed. Furthermore, several images can be contained in containers. Each image is assigned to exactly one damage description within the report. If several images are kept in containers, a subfolder can be created for data management reasons. The image should be stored in this folder under a comprehensible and unique name.

Payload Triples

RequestedReports.rdf defines links to describe for which components a visual inspection is contracted. Thus, links between the components (*BridgeModel.ifc*), the classifications (*BridgeClassification.rdf*) and the report template (*ReportTemplate.xsd*) are defined. On this basis it can be checked that at least one report has been created for all components to be inspected based on the given template.

DamagePlacement.rdf contains the links between the bridge model (*BridgeModel.ifc*) and the placement of information regarding the condition assessment (*LocalPlacement.ifc*), which enables, for example, the assignment of a damage area relative to a bridge component. This allows for the creation of links between parts (e.g., *IfcBuiltElement*, *IfcElementAssembly* or *IfcElementComponent*) and surface damages (*IfcSurfaceFeature* - type DEFECT) for visual condition assessment.

ReportLinking.rdf contains the links between the individual reports and the corresponding components and damage descriptions. A separate report and link should be created for each component. One report usually contains several damage images. The linking can be done with the help of different concepts (compare Chapter 2.4). The document for localization (*LocalPlacement.ifc*) contains various supplementary IFC objects (e.g. *IfcExternalInformation*, *IfcFeatureElement* or also *IfcPropertySet*). Identifiable elements of the report can be linked to different positions in the IFC model. The link is always made with the help of the GUID of the additional information.

ReportVisualDetails.rdf contains the links between the description or evaluation of an individual damage, the exact position of the damage in the model (*LocalPlacement.ifc*) and the corresponding image of this damage.

Figure 8 shows a schematic representation of the presented documents of the information container with the possible links to exchange information about the visual status of a bridge.

Currently, a detailed evaluation of the container's structure is being developed. For this purpose, however, an implementation must be carried out and test data must be prepared in a meaningful way.

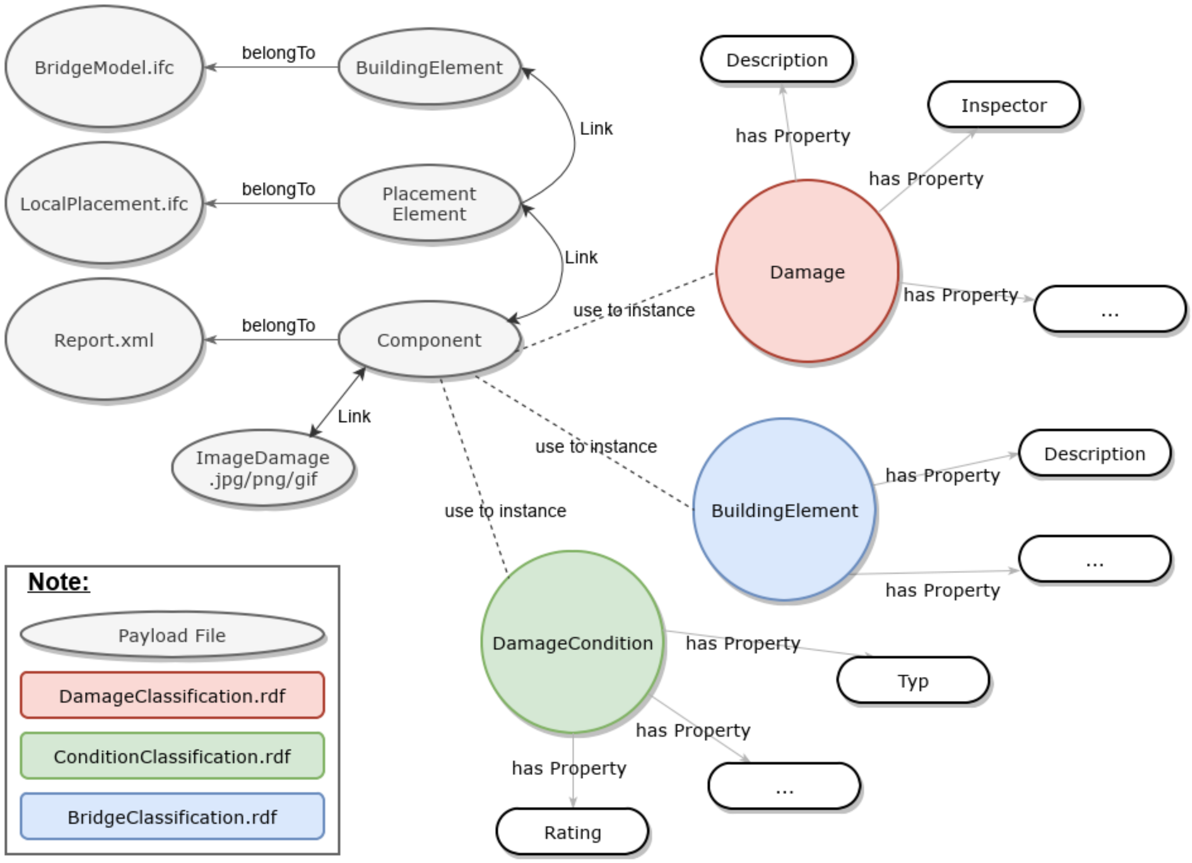

Figure 8 Overview of the relations of the information container for the visual inspection of bridges

A similar overview of information links can also be automatically created for instantiated data using ontology implementation applications such as Protégé (https://protege.stanford.edu/). This allows the user to see the entire linked data network at a glance. In the same way as the information container presented here, the exchange requirements for the other two use cases are created. However, only the differences and additions are presented.

3.3.2 Dynamic response analysis for bridges

In the report of WP3.1 the Vehicle-Bridge-Soil Dynamic Interaction Model (VBSI) for damage analysis of bridges was presented (Prendergast et al. (2016)). With a fixed mounted sensor, the frequency of the bridge is determined under consideration of crossing vehicles. An exact numerical analysis of the sensor data allows the detection and monitoring of scour around bridge foundations. For this type of condition assessment, the information such as measurement data of the sensor, as well as the analysis of the scour at the foundation, are returned as results. The corresponding structure of the two information containers is shown in Figure 9.

Exchange Requirements Model		
Name:	Dynamic response analysis for bridges	
Identifier:	ER1_ICDD_Inspection_Assignment	
Description:	**Name**	**Type**
	Index.rdf	rdf
Ontology Resources:		
	Container.rdf	rdf
	LinkSet.rdf	rdf
	DynamicSemantics.rdf	rdf
Payload Dcuments:		
	BdrigeSensorModel.ifc	ifc
	SensorDataTemplate.xsd	xsd
	ReportTemplate.xsd	xsd
Payload triples:		
	RequestedReports.rdf	rdf

Exchange Requirements Model		
Name:	Dynamic response analysis for bridges	
Identifier:	ER2_ICDD_Condition_Assessement	
Description:	**Name**	**Type**
	Index.rdf	rdf
Ontology:		
	Container.rdf	rdf
	LinkSet.rdf	rdf
	DynamicSemantics.rdf	rdf
Payload Documents:		
	BdrigeSensorModel.ifc	ifc
	SensorData.xml	xml
	Report.xml	xml
Payload Triples:		
	SensorLinking.rdf	rdf
	ReportLinking.rdf	rdf

Figure 9 Structure of information containers for dynamic response analysis for bridges

Ontology Resources

Container.rdf and *LinkSet.rdf* are the standard ontologies for defining the documents and links contained in the container. *DynamicSemantics.rdf* allows the user to insert and use a self-defined ontology within the container.

Payload Documents

BridgeSensorModel.ifc describes the as-built model of the bridge using the IFC format (compare Chapter 3.3.1). It is assumed that the sensors to be evaluated are described as separate objects in the IFC model. For this purpose the IFC class *IfcSensor* can be used. The sensor can be positioned very precisely and provided with a geometry. Further information can be taken from Chapter 4.

SensorDataTemplate.xsd specifies the scheme for recording the individual data sets. The template is defined according to the used sensor. Often a table-oriented data structure is used. In this case, the displacements, velocities, and accelerations can be recorded for every vehicle driving over the bridge.

SensorData.xml contains the measurement data of the sensor. The measurement data are stored as raw data. The data are then used as input data for the numerical analysis using the Vehicle-Bridge-Soil Dynamic Interaction approach.

ReportTemplate.xsd specifies the data schema to describe the analysis result. Detailed information, which the analysis result provides, can be taken from Chapter 3.1. Besides the result data, the assumptions for the evaluation should also be documented.

Payload Triples

RequestedReports.rdf defines links to describe for which bridge or part of bridge a Vehicle-Bridge-Soil Dynamic Interaction Model should be created. On this basis it can be checked that at least one report has been created based on the given template.

SensorLinking.rdf contains the links between used sensors of the bridge model and the actual measurement data of the respective sensor. In principle, different documents can also be linked for a sensor with measured values depending on the measured values as well as the measurement times.

ReportLinking.rdf contains the links between the analysis results and the measurement data of the sensors. You can link the whole report or only parts of the report that can be identified. The design of the linking has to be considered further.

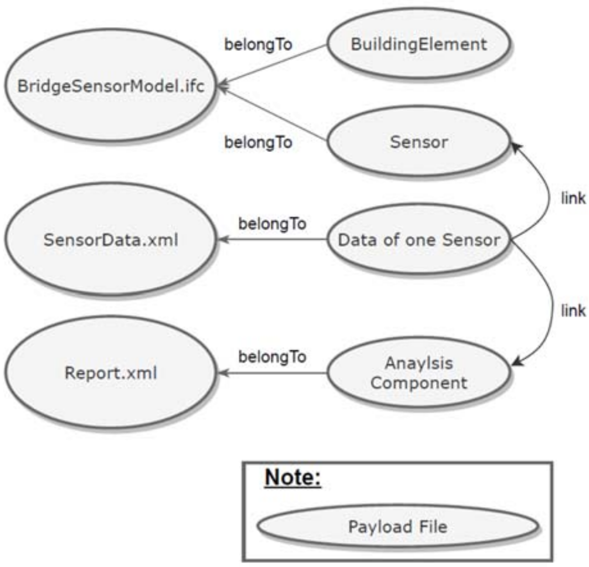

Figure 10 Overview of the relations of the information container for dynamic response analysis for bridges

3.3.3 Ground penetrating radar analysis for roads

The detection of road conditions with the Ground Penetrating Radar (GPR) is a proven and widely used technique. This is a non-destructive test for roads. It enables the asset owner to detect cavities within the pavement and assess the thickness of the pavement layers. With an integrated camera the surface of the pavement can also be recorded for damage detection.

However, an inspection with this technique can create huge amounts of raw data, which does not give any direct result. Rather, it requires further processing for damage detection. In general, the raw data are stored and managed in a central repository. The evaluation of the road condition and the findings of pavement surface damage or pavement structural damage are reported to asset managers. To meet this requirement, the two containers are created as shown in Figure 11.

Exchange Requirements Model		
Name:	Ground Penetrating Radar for roads	
Identifier:	ER1_ICDD_Inspection_Assignment	
Description:	**Name**	**Type**
Index:		
	Index.rdf	rdf
Ontology:		
	Container.rdf	rdf
	LinkSet.rdf	rdf
	DynamicSemantics.rdf	rdf
	PavementClassification.rdf	rdf
Payload Dcumente:		
	RoadModel.ifc	ifc
	RoadSections.ifc	ifc
	ReportTemplate.xsd	xsd
	DrillCoreTemplate.ifcxml	xml
	GPRAnalysis.xsd	xsd
Payload triples:		
	RequestedReports.rdf	rdf

Exchange Requirements Model		
Name:	Ground Penetrating Radar for roads	
Identifier:	ER2_ICDD_Condition_Assessement	
Description:	**Name**	**Type**
Index:		
	Index.rdf	rdf
Ontology:		
	Container.rdf	rdf
	LinkSet.rdf	rdf
	DynamicSemantics.rdf	rdf
	PavementClassification.rdf	rdf
Payload Dcumente:		
	RoadModel.ifc	ifc
	RoadSections.ifc	ifc
	Report.xml	xml
	DrillCores.ifc	ifc
	GPRData.xml	xml
Payload triples:		
	ReportLinking.rdf	rdf
	DrillCoreLinking.rdf	rdf
	GPRLinking.rdf	rdf

Figure 11 Structure of information containers for ground penetrating radar analysis for roads

Ontology Resources

Container.rdf and *LinkSet.rdf* are the standard ontologies for defining the documents and links contained in the container. *DynamicSemantics.rdf* allows the user to insert and use a self-defined ontology within the container.

PavementClassification.rdf is an ontology to classify the individual layers of a road. Since the classification of the pavement is carried out according to national standards, the definition of this ontology should correspond to national regulations. For example, the okstraOWL from the BASt project “Analysis of application possibilities of linked information (Linked Data) and ontologies and related technologies (Semantic Web) in the road sector” can be used for the German classification according to the “Objektkatalog für das Straßen- und Verkehrswesen” (OKSTRA).

Payload Documents

RoadModel.ifc describes the as-built model of the road using the IFC format. However, this should only be an extract, i.e. only the most important elements, sections and information should be extracted from the complete as-built model. A Model View Definition (MVD) is usually created for this purpose. This must contain all relevant geometric and semantic information required for the analysis ordered. The as-built model is not changed during the analysis. Additional information to be managed later in the BIM data environment is added as external information. In particular, an additional document in IFC format is added to collect information on the thickness of the pavement for the section under investigation.

RoadSections.ifc describes the areas which are to be analysed by using GPR. For this purpose, a simple specification of stations can be made with the help of so-called referent objects. A referent defines a position at a particular offset along an alignment curve.

ReportTemplate.xsd defines a data schema for the results using GPR technology in the form of a report using XML. This document can be understood as a kind of form to be filled in by the contractor. Mandatory and optional fields can be specified. In order for the reports to be evaluated automatically, information should be provided as detailed as possible. The template is usually based on national guidelines.

Report.xml contains the analysis results considering the defined template. Due to the fluctuations of the ground penetrating radar, homogeneous sections are formed. Together with the findings from the bore cores these lead to the actual assumed road structure. The report can be checked for completeness and formal correctness based on the defined template. It is also possible that the information container contains several reports. However, the reports must also individually fulfil the defined scheme.

DrillCoreTemplate.ifcxml defines a set of properties using the IFC format to further describe drill cores. For this purpose, so-called *IfcPropertySetTemplates* are used. Drill cores are necessary to calibrate the results of the ground penetrating radar. The classification of the road structure is based on the given ontology.

DrillCore.ifc stores one or more drill cores using the IFC format and the defined property sets. The individual drill cores are linked to the corresponding road sections and precisely located. In combination with the model of the road the drill cores can be visualized and evaluated with the help of suitable software tools.

GPRAnalysis.xsd defines the data scheme for storing the raw data of the ground penetrating radar. The measuring system consists of a transmitter and receiver unit. The transmitting antenna emits electromagnetic pulses with a high repetition rate via pulse generators. Layer thicknesses with different electromagnetic properties and small-scale structures, such as cavities, reflect or refract the waves emitted by the transmitting antenna. A lot of data is recorded at a very high frequency, which has to be evaluated afterwards.

GPRAnalysis.xml stores the pipe data for a measurement using ground penetrating radar. The data acquisition was usually done per driving direction. If several sections or lanes are to be measured, a separate file exists for each measurement. It is also possible to split a lane into several files.

Payload Triples

DrillCoreLinking.rdf contains the links between drill cores, their assignment to a road section and which drill cores were used for which calibrations within the report to create homogeneous sections.

ReportLinking.rdf contains the links between the inspected road section and the average layer thicknesses based on the measurement data. A new segmentation can also be made for the inspected road section. In this case, however, the division (*RoadSections.ifc*) would also have to be adjusted.

GPRLinking.rdf contains the links between the raw data and the corresponding averaged layer thicknesses, which are listed in the report. For this purpose, the measurements are combined to homogeneous areas.

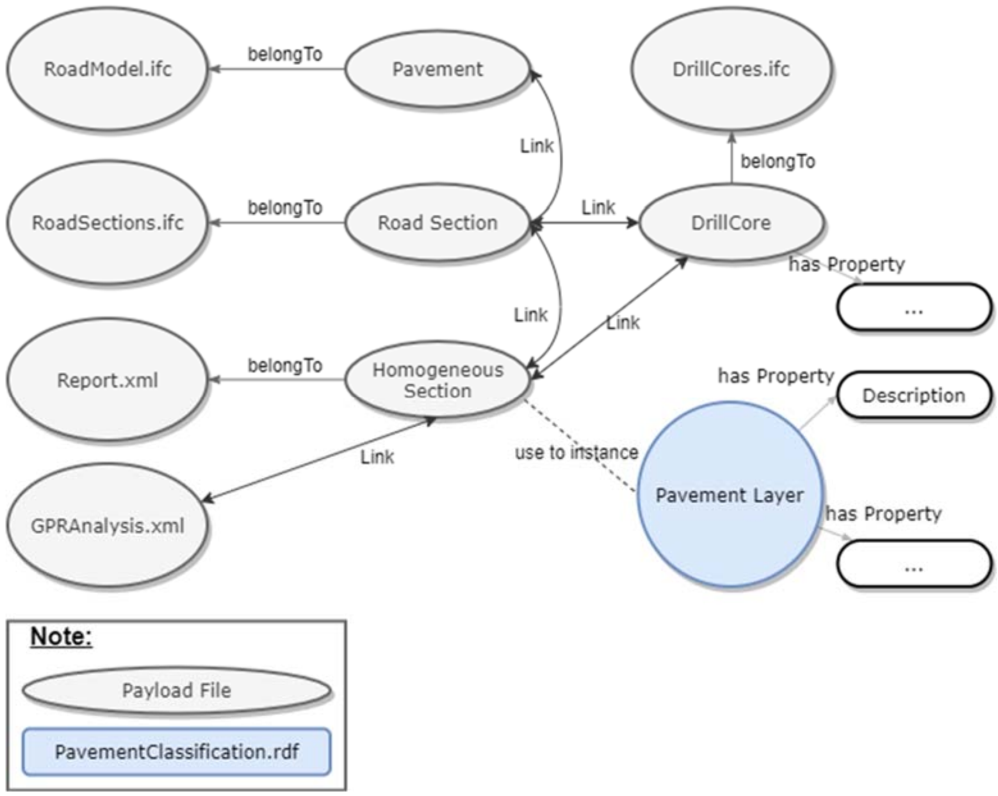

Figure 12 Overview of the relations of the information container for ground penetrating radar analysis for roads

4 Analysis of the IFC using for condition assessment

In recent years, the Industry Foundation Classes have been continuously expanded and now, in Version 4.3 Release Candidate 2, they include new classes for infrastructure modelling. In particular, the following new classes for the description of road entities are available:

IfcRoad: A route built on land to allow travel from one location to another, including highways, streets, cycle and foot paths, but excluding railways. As a type of Facility, Road provides the basic element in the project structure hierarchy for the components of a road project.

IfcKerb: A border of stone, concrete or other rigid material formed at the edge of the carriageway or footway.

IfcOpenCrossProfileDef: A two-dimensional open profile defined by widths and slopes for the use within the swept surface geometry.

IfcSectionedSurface: A kind of surface constructed by sweeping potentially varying open cross sections along a curve horizontally.

IfcCourse: A built element whose length greatly exceeds its thickness and often also its width, usually of a single material laid on site on top of another horizontal or nearly horizontal built element.

IfcPavement: Type of built element in a road or other paved area to provide an even surface sustaining loads from vehicles or pedestrians, usually comprising several courses.

Furthermore, important properties for the modelling of roads were also provided. In the following, only some properties are listed. An overview can be found in the official documentation for IFC 4.3 RC2:

ApplicationTemperature: Indicates the ambient temperature at which the course is applied.

WeatherConditions: Indicates the weather conditions during the application of the course.

PavementRoughness: An assessment of the functional condition of the pavement surface indicated as an index according to the International Roughness Index (IRI).

PavementTexture: Characterization of pavement texture by mean profile depth (ISO 13473-1:2019).

DesignSpeed: Speed selected in designing a new road or in modernizing, strengthening or rehabilitating an existing road section, to determine the various geometric design features of the carriageway that allow a car to travel safely at that speed, under normal road surface and weather conditions.

DesignTrafficVolume: The traffic volume used for planning and design purposes specified as the number of vehicles per day.

LaneWidth: Standard nominal width of one through lane.

Additional classes and property sets for the modelling of bridges have also been included in the current release candidate.

IfcBridge: A bridge is civil engineering work that affords passage to pedestrians, animals, vehicles, and services above obstacles or between two points at a height above ground.

IfcDeepFoundation: Deep foundation is a type of foundation that transfers loads deeper than shallow foundation below the soft soils not capable of bearing the weight of the above structure. Depending on the soil strength it might have to reach down to the rock layer.

For the representation of important bridge elements no new classes were introduced. Instead, existing types were extended to describe the classes in more detail. For example, the class *IfcBeamTypeEnum* now has a value *GRIDER_SEGMENT*. In addition to the description of individual elements of a road or bridge, it is possible to provide further information for modelling surface damages or other changes of the surface.

IfcFeatureElement: A feature element is a generalization of all existence dependent elements which modify the shape and appearance of the associated master element.

IfcSurfaceFeature: A surface feature is a modification at (onto, or into) of the surface of an element. Parts of the surface of the entire surface may be affected. The local placement is defined by the *IfcLocalPlacement*, which defines the local coordinate system that is referenced by all geometric representations. In case of features which are part of an element type, absolute placement into the type object's implied coordinate system shall be used. In case of features which are voiding an element occurrence, the *PlacementRelTo* relationship of *IfcLocalPlacement* shall point to the local placement of the respective element. There are also several predefined types that can be used for classification. The types (*IfcSurfaceFeatureTypeEnum*) are shown in the following figure.

Constant	Description
MARK	A point, line, cross, or other mark, applied for example for easier adjustment of elements during assembly.
TAG	A name tag, which allows to identify an element during production, delivery and assembly. May be manufactured in different ways, e.g. by printing or punching the tracking code onto the element or by attaching an actual tag.
TREATMENT	A subtractive surface feature, e.g. grinding, or an additive surface feature, e.g. coating, or an impregnating treatment, or a series of any of these kinds of treatments.
DEFECT	Detected defect on the surface of an element, such as corroded or eroded area.
HATCHMARKING	surface markings defined by enclosed 2d shape with defined hatch fillings.
LINEMARKING	2D lines painted on pavement surfaces to form boundaries, centrelines and edge markings.
PAVEMENTSURFACEMARKING	Painted or chemical lines or symbols on the surface of pavements (a road or paved area)
SYMBOLMARKING	Surface markings that convey information in the form of symbols and shapes such as arrows, text or pictorial symbols.
NONSKIDSURFACING	Paint or surfacing to prevent sliding or skidding.
RUMBLESTRIP	Raised and often textured strips on road center line or on shoulder, or across lanes to alert drivers by vibration and noise. Also Jiggle bars. NOTE Definition from PIARC: Narrow raised and often specially textured strips across or alongside the carriageway, generating noise and vibrations through vehicles in order to alert drivers and encourage them to slow down for particular hazards.
TRANSVERSERUMBLESTRIP	Type of rumble strip running across lane(s).
USERDEFINED	A user-defined type of surface feature.
NOTDEFINED	An undefined type of surface feature.

Figure 13 Predefined types for surface features (buildingSMART International)

The ability of IFC to dynamically add individual sets of properties means that all possible information about a particular area on the surface of an element of a road or bridge can be described. The information can be positioned both absolute and relative. The following classes can essentially be used for this purpose:

IfcLocalPlacement: A local placement defines the relative placement of an element in relation to the placement of another element or the absolute placement of an element.

IfcLinearPlacement: A linear placement provides a specialization of object placement in which the placement and axis direction of the object coordinate system is defined by a reference to a curve.

IfcAxis2PlacementLinear: This class provides location and orientation to place items in a three-dimensional space confined to the context of a curve.

IfcAlignment: An alignment is used to define a reference system to position elements mainly for linear construction works, such as roads, rails, bridges, and others. The relative positioning along the alignment is defined by the linear referencing methodology.

IfcReferent: Referent defines a position at a particular offset along an alignment curve. Can be used to indicate domain-specific design parameters (via property sets) at locations along an alignment curve.

4.1 Classification

In order to describe the digital model according to the respective guidelines of the national asset management systems, the IFC scheme offers the possibility of submitting the object elements with an individual classification. For example, the well-known classifications Uniclass (GB), DIN 276 for cost estimation or ASB-ING (DE) can be integrated in this way. The IFC-entity *IfcClassification* as well as *IfcClassificationReference* can be connected by a relation-entity *IfcRelAssociatesClassification* with parts of spatial structure elements (*IfcBridge*), physical elements *IfcBuilingElement* (as a subtype of *IfcElement*) or positioning elements (Figure 14).

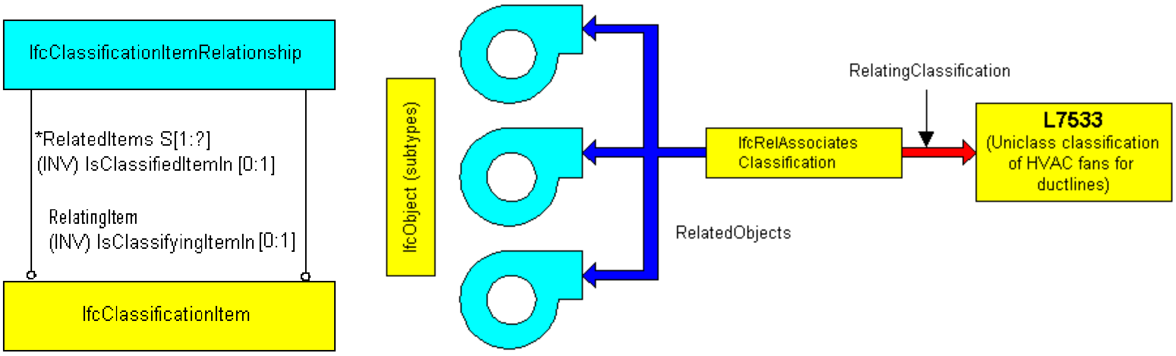

Figure 14 Classification concept of the IFC (buildingSMART International)

In the following example (see Figure 15) the kerb is modeled as an *IfcBuiltElement*. This element is classified using *IfcClassificationReference*, which refers to the ASB-ING of existing infrastructure data for the maintenance system in Germany.

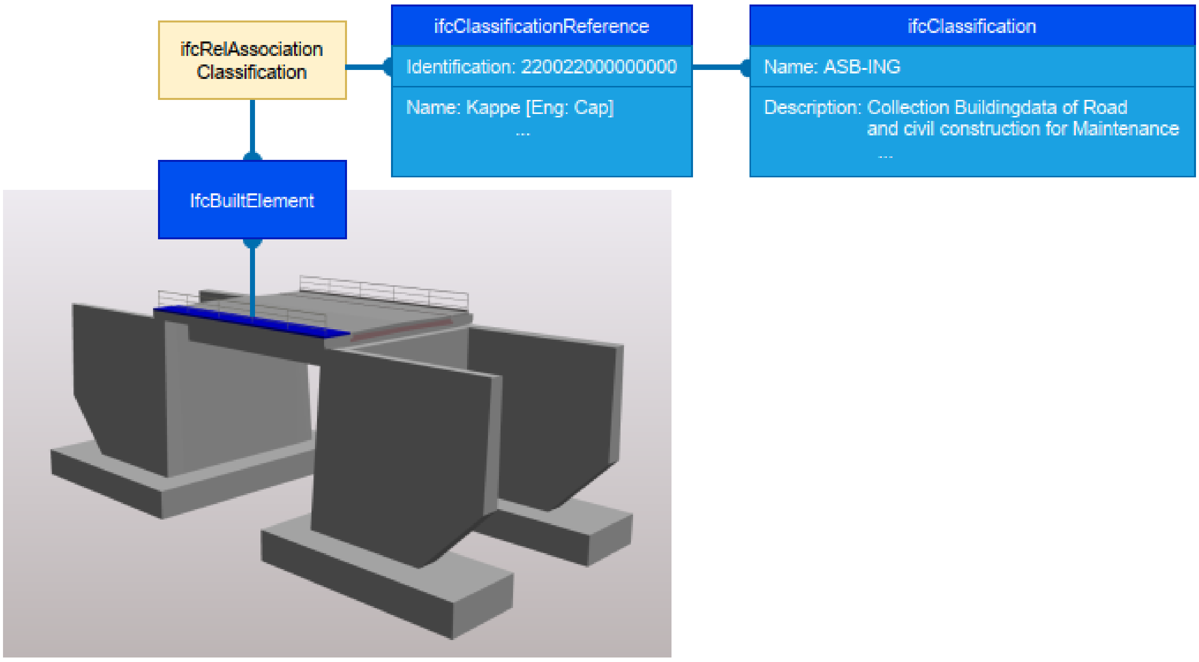

Figure 15 Classification for a bridge element

4.2 Use-Defined Property Sets

As basic information, relevant semantic information of the design element should be included directly in the IFC model. This semantic information could be derived from various sources, e.g. from construction, previous inspections or maintenance work. Semantic information can easily be added as a property set. For the feedback of the condition assessment, the inspection result can be directly added to the design model as a user-defined property set.

To transfer the important semantic information of a component directly into the IFC model, predefined PropertySets should be provided in the IFC schema. The extension of the IFC schema with *IfcPropertySetTemplate* in version IFC4 provides the flexibility to describe an element with individual semantic information. With *IfcPropertySetTemplate* the properties required by the asset owner can be defined in advance as a template. The new *IfcPropertySet* is referenced to the component by *IfcRelDefinesByProperties* (see Figure 16). The following example shows how to use the custom property and property sets for a bridge element (see Figure 17).

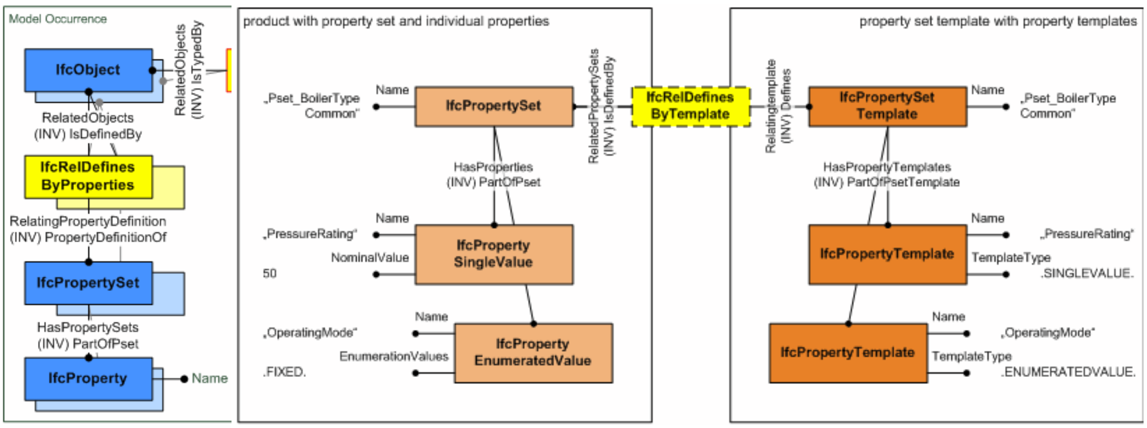

Figure 16 Property template concept of the IFC (buildingSMART International)

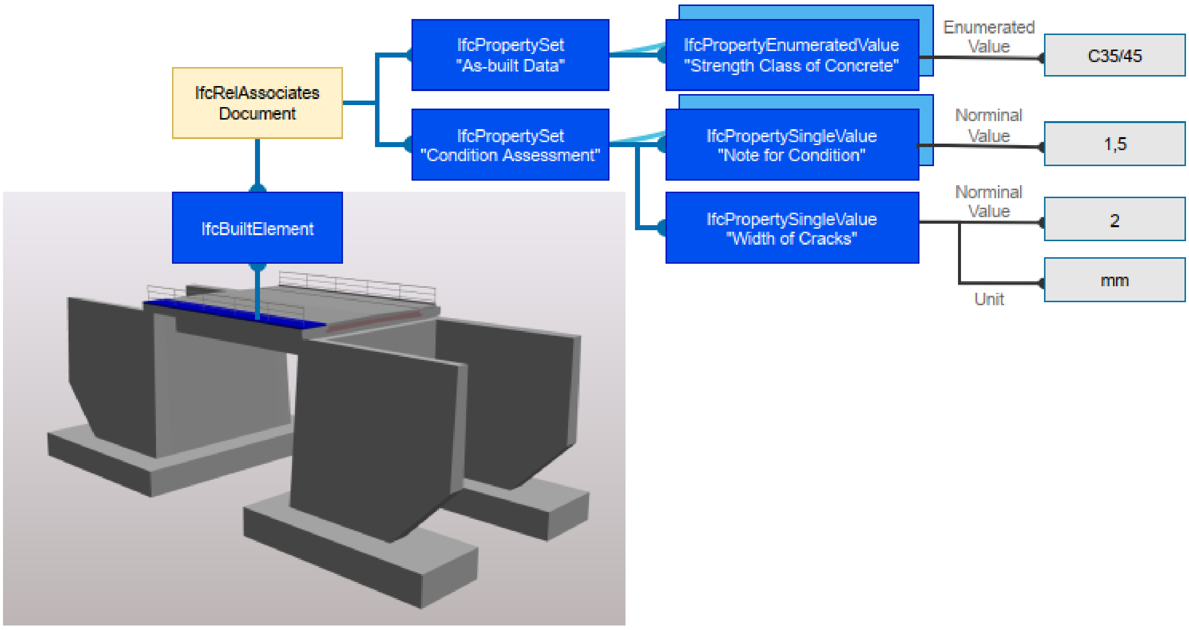

Figure 17 Assigning a property set to element of a bridge

4.3 *Linking external documents*

As discussed above, damage to the component is recorded as part of the inspection result using images and documents from the non-destructive testing process. A report on the inspection is prepared and submitted to the owner of the infrastructure. The information obtained, such as images or documents, are external files that can also be linked to the IFC model using *IfcDocumentInformation* using a URI. *IfcDocumentInformation* contains comprehensive attributes that describe the metadata of a document to be linked (see Figure 18).

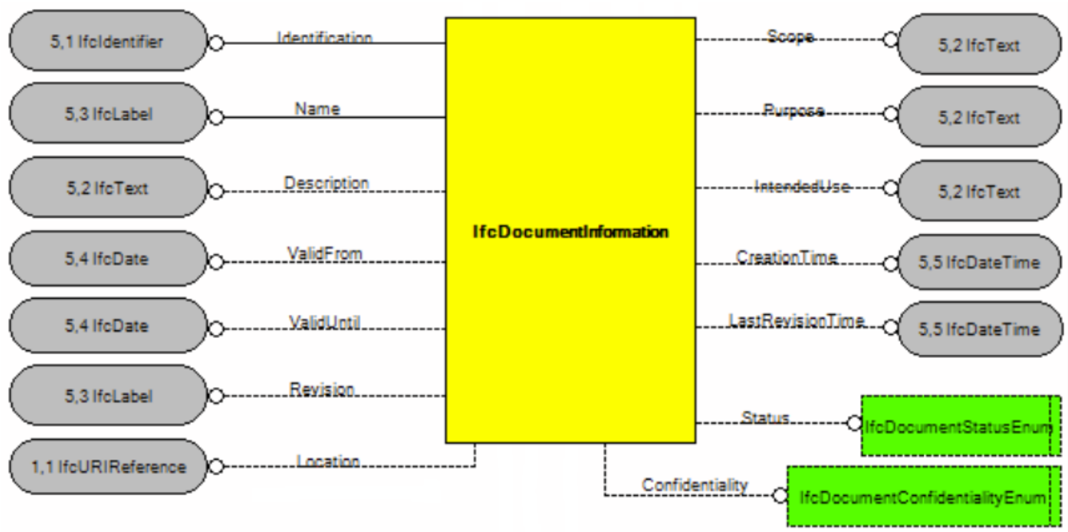

Figure 18 Attributes of the class *IfcDocumentInformation* (buildingSMART International)

Another possibility is to use *IfcDocumentReference*. A disadvantage is the missing possibility to capture the metadata of a document by using user-defined attributes. This problem can be avoided by referencing *IfcDocumentInformation*. With the help of the *IfcRelAssociatesDocument* relationship the document can be linked to a part as shown in Figure 19. As already mentioned, documents are stored externally and referenced only by location information (URI), which can lead to difficulties in data exchange. If the documents are transferred incorrectly or the storage location of the documents is changed, the references to the documents become invalid.

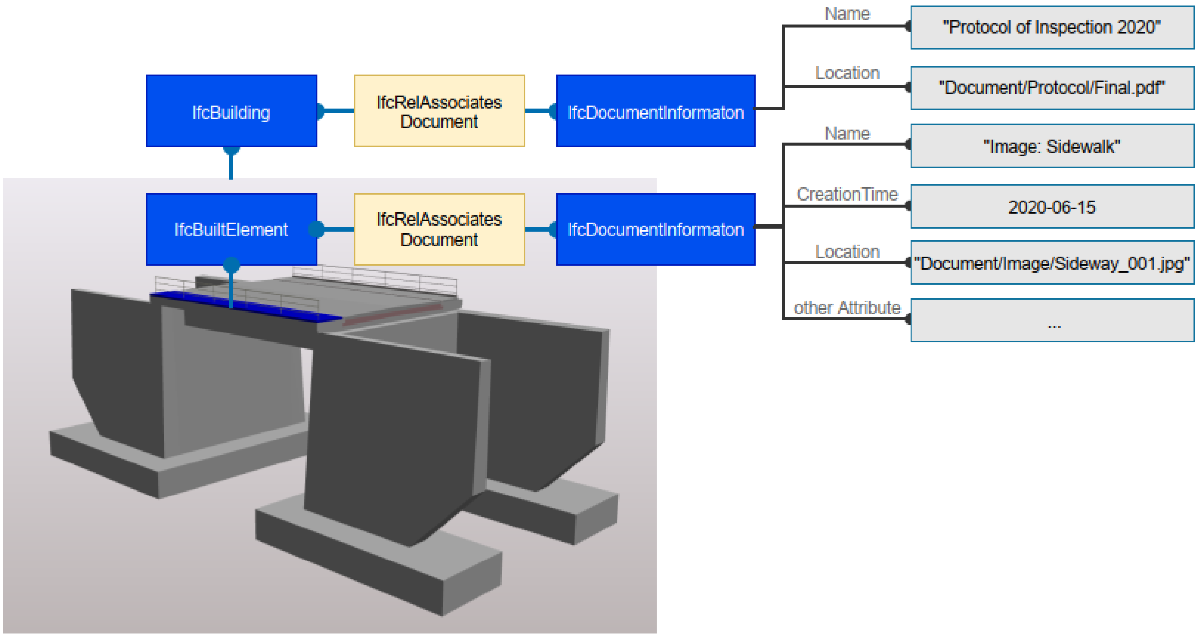

Figure 19 Assigning an external document to a bridge element with some metadata

4.4 *IFC for Sensor Definition*

Nowadays, sensors are often used to monitor the condition of a building or to support the control of technical equipment. Information about a sensor can also be mapped in an IFC model. For this, the class *IfcSensor* can be used as a subtype of *IfcDistributionControlElement*. To describe the sensor, different sensor types are predefined in *IfcSensorTypeEnum*. The existing sensor types clearly show that sensors are mainly intended for technical building equipment (heating, ventilation and air conditioning). However, it is also possible to employ user-defined sensor types. This makes it possible to model sensors with the correct type designation in the IFC model, e.g. sensors such as accelerometers or stress detectors whose measurement data are used for stability analysis. With the relationship *IfcRelAssignsToProduct* a sensor can be assigned to a component. In addition, there are extensive predefined property sets that can also be used to describe the metadata of a sensor. For example, the manufacturing information can be supplemented with the property sets *PSet_ManufacturerOccurrence* and *PSet_ManufacturerTypeInformation*. For additional properties a user-defined property set can be added to a sensor element. Figure 20 shows an example of a component linked to a sensor.

The number of installed sensors depends strongly on the application. In practice, several sensors are often bundled into one measuring system to realize the monitoring of certain structural changes. To create a correct monitoring system with sensors, a proposed extension of the IFC data scheme is shown in section 4.6.

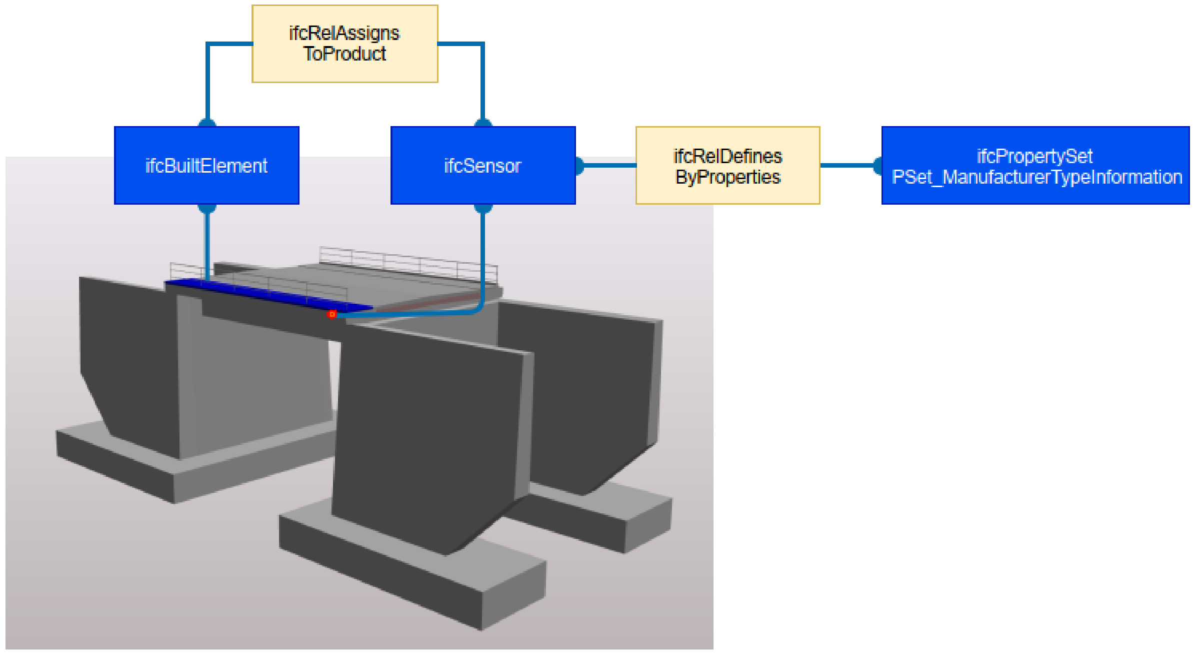

Figure 20 Integration of a sensor for monitoring a bridge component

4.5 IFC Extension for Damages

An extension to the IFC standard for structural testing of bridges is proposed in Tanaka et al (2016). The concepts provide new IFC entities for the modelling of inspection areas with *Ifc-MeasuredRegion*, repaired areas with *IfcRepairedRegion* and deterioration or damage with *IfcDegradation* or *IfcDegredationElement*. The *IfcDegradationElement* is intended to present the temporal development of damage. It describes the condition of a damage at a certain inspection with time data. With the new relation entity *IfcRelConnectsToMeasureRegion*, the instance generated as type of the new entities will be connected with standard bridge elements. With *IfcRelConnectsToTimeVariations* the damage can be linked at different timestamps (see Figure 21). In addition, *IfcTasks* can be used to define an inspection, assessment or maintenance in an IFC model with the *TaskTime* and *PredefinedType* attributes added.

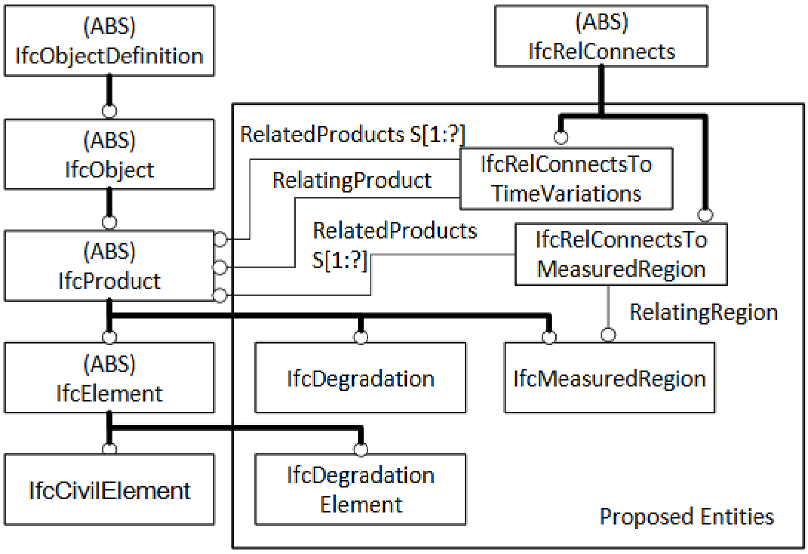

Figure 21 IFC extension for damage modelling in Tanaka et al (2016)

4.6 IFC Extension for Monitoring

The method presented in work package 3.1 for the analysis of sediment level or bed elevation near a structure (see Figure 22) can be understood as a Structure Health Monitoring (SHM) system. An SHM system uses sensors to monitor the stability of a structure. By extending the IFC, a complete SHM system with sensor networks could be digitally modeled.

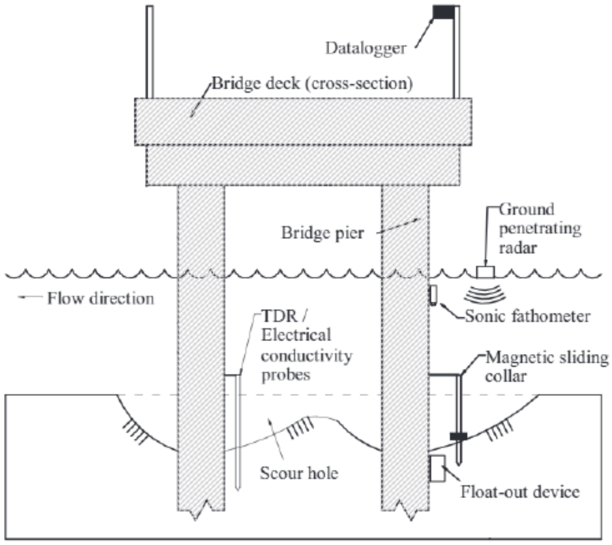

Figure 22 Scour monitoring instrumentation in Prendergast et al (2013)

In Theiler & Smarsly (2018) the extension of IFC with comprehensive user-defined IFC entities for sensor technology is shown. The existing IFC schema is not able to capture a sensor network needed for a SHM system. However, IFC offers the possibility to extend the schema with user defined entities. By extending the IFC schema, the entities for a sensor network is integrated in the IFC schema with semantic information. The basic idea is to generate a reference model by taking into account the existing standard for SHM along with sensor modeling languages and ontologies. The relevant information for monitoring can be collected in a so-called "monitoring-related mode". By integrating the two models, the important semantic information about the sensor, the standard of the SHM and monitoring information will be matched (see Figure 23). If the existing IFC object model (version IFC 4) is extended by the semantic model, so-called IFC monitors are created.

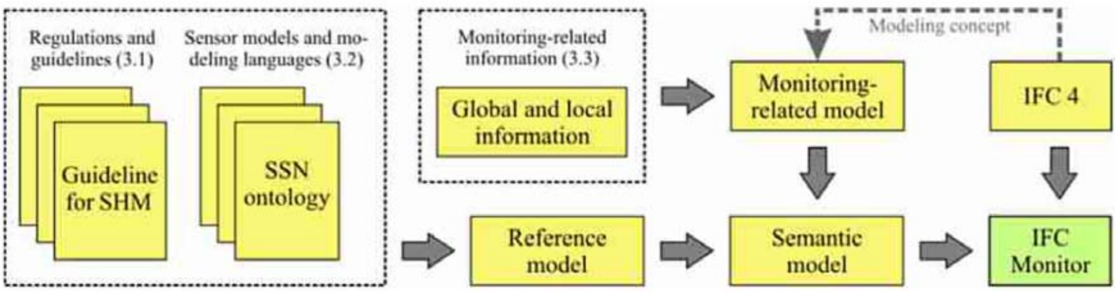

Figure 23 Conceptual approach towards IFC-based mapping of monitoring-related information in Smarsly & Tauscher (2016)

Theiler & Smarsly (2018) added three entities and one enumeration type to the IFC schema (see Figure 24). The entities include sensor nodes (*IfcSensorNode*), sensor networks (*IfcSensorNetwork*), and SHM systems (*IfcSHMSystem*). The *IfcSensorNode* entity describes a single sensor node and is a subtype of the *IfcProduct* entity, because a sensor node is an object that appears in a spatial or geometric context, thus enabling assignments of geometric representations and locations to sensor nodes. A sensor network (*IfcSensorNetwork*), according to the semantic model, is a collection of nodes, i.e. sensor nodes and base stations. A structural health monitoring system (*IfcSHMSystem*) is a composition of functionally related entities. Similar to *IfcSensorNetwork* entities, every SHM system is a subtype of *IfcSystem*.

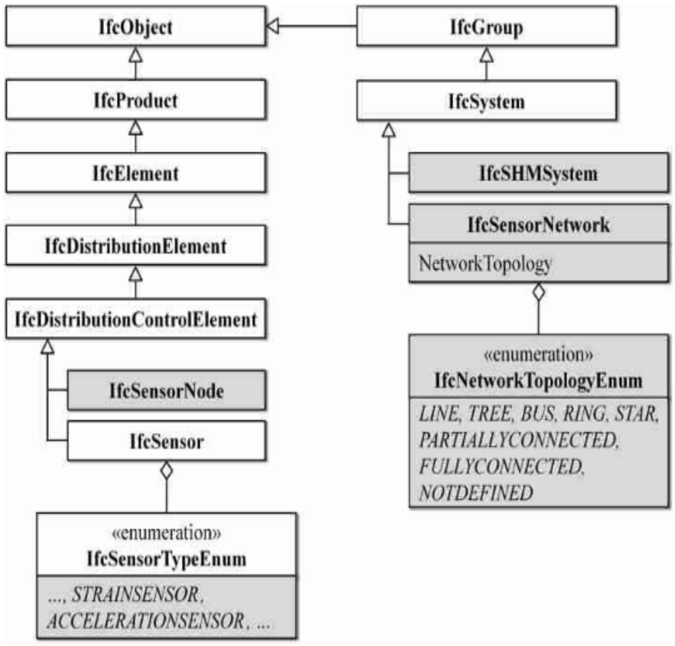

Figure 24 Proposed IFC Monitor extension in Theiler & Smarsly (2018)

5 Conclusions

The current analysis has shown that even with the current IFC 4.3 RC2 standard, essential information for condition assessment can be modelled. For this purpose, however, it must be defined exactly which concepts of IFC should be used. Furthermore, user-defined properties must be specified with the help of property sets. In addition, there is always the possibility to link additional information in the form of external documents. Information containers can be very useful for linking and exchanging linked information or documents. For a problem-free data exchange the information to be exchanged must be described with the help of ontologies and metadata. The exact design of the ontologies and metadata is still work in progress.

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