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Call 2018 Building Information Modelling (BIM)
Final Programme Report

September 2022

Call 2018 Building Information Modelling (BIM) Final Programme Report

CEDR Contractor Report 2022-11

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This Report is an output from the CEDR Transnational Road Research Programme Call 2018: Building Information Modelling (BIM). The research was funded by the CEDR members of Austria, Belgium – Flanders, Denmark, Finland, Germany, Netherlands, Norway and Sweden.

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Glossary

AMS	**Asset Management System**
API	Application Protocol Interface
BIM	Building Information Modelling
BMS	Bridge Management System
IAMS	Infrastructure Asset Management System
IFC	Industry Foundation Class
NRA	National Road Authorities
MDD	Master Data Dictionary
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
AMS	Asset Management System
OTL	Object Type Library

Introduction

In 2018 the CEDR Transitional Road Research Programme (funded by Austria, Belgium-Flanders, Denmark, Finland, Germany, Netherlands, Norway and Sweden) commenced a research programme on BIM (Building Information Modelling) with the aim to provide a better understanding of how BIM principles could be practically applied within the European highways industry.

The research programme aimed to answer the following key questions for European road authorities:

A. How to incorporate national classification systems into the framework of the European road OTL and how to benefit from these classifications on an individual CEDR member level. The results from the Interlink project should be considered in this approach.
B. How to benefit from open standards like IFC and IFC Road throughout the lifecycle considering the European road OTL.
C. How to benefit from scanning/sensor data to enrich asset management systems.
D. How to combine the strength of traditional techniques with the strength of the Interlink approach based on Linked Data/ semantic web techniques.
E. How to engage software industry to align their roadmap for development with the needs of CEDR members

The research call funded two projects:

- CoDEC – Connected Data for Effective Collaboration
- AMSfree – Exchange and exploitation of data from Asset Management Systems using vendor free format

This report presents the methodology and outcomes of the two projects and provides an overview of the outcomes of the final conference on this Call, which was held in Stockholm on 24-25 May 2022.

At the end of this report recommendations are given on potential next steps in the further dissemination and implementation of the outcomes of CoDEC and AMSfree research projects.

PART 1 THE PROJECTS

CoDEC – Connected Data for Effective Collaboration

Project facts

Duration: October 2019 – May 2022

Budget: 749 995.00 EUR

Coordinator: TRL Ltd. (United Kingdom)

Partners: BRRC (Belgium), ZAG (Slovenia), Bexel Consulting (Slovenia), LNEC (Portugal), Royal HaskoningDHV (RHDHV) (Netherlands), Forum of European National Highway Research Laboratories (FEHRL) (Belgium)

Website: https://www.codec-project.eu/

Project overview

CoDEC was based on the development of a methodical framework for data (the Data Dictionary), which was translated into a machine-readable framework (the ontology) to enable interoperability in AMS and BIM data. This provides a step on the journey to the goal of making data available seamlessly when and where needed across different types of management systems. The AM4INFRA (AM4INFRA,2018) and INTERLINK (INTERLINK, 2018) research projects, funded by CEDR, had already taken the first steps towards a standardised format for data sharing, by developing a European Road Object Type Library (EurOTL), based on the IFC (Industry Foundation Class) standard. CoDEC built on these to encompass the data used in asset management decision making processes - including data from new technologies such as scanning systems and sensors - to develop standardised methods to automate the integration of this wider data.

Figure 1 provides an overview of the CoDEC processes and outcomes. CoDEC undertook a literature review, stakeholder engagement and desktop research to understand the as-is situation, the aspirations of NRAs and the challenges they face. This was used to determine the requirements for the CoDEC Data Dictionary and the CoDEC Ontology for three key infrastructure assets: Roads, Bridges and Tunnels. Building on this Ontology CoDEC produced a software application (Application Protocol Interface, API) for implementation of the developed methods and applications in three demonstration pilot projects.

The final outcomes of CoDEC were therefore the CoDEC Data Dictionary, the CoDEC Ontology, and an OpenAPI (CoDEC API), all of which are expandable to cater for the needs of individual NRAs, and implementable within their systems and processes.

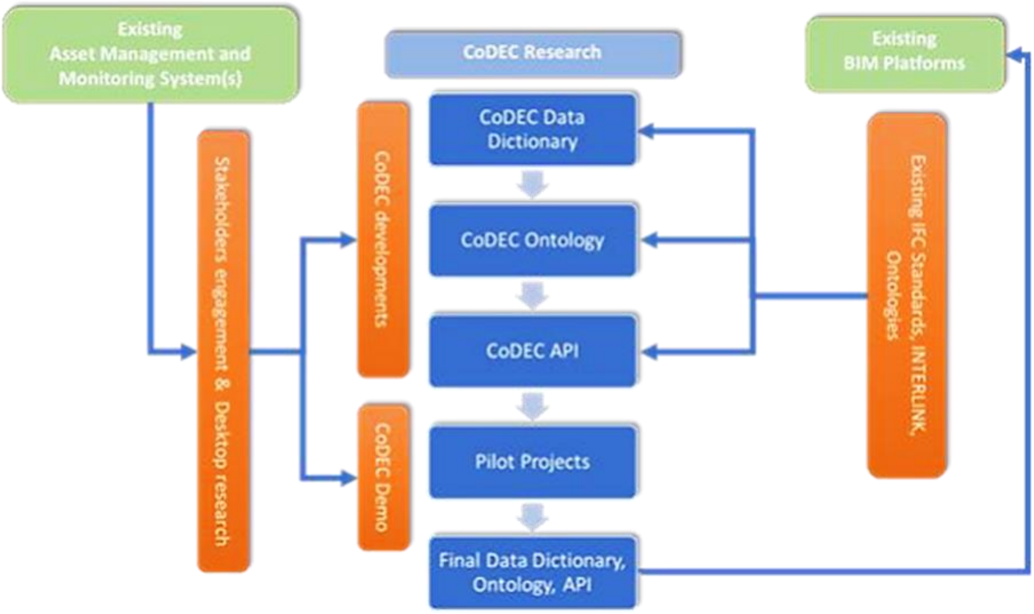


Figure 1: CoDEC Process and Outcomes

Work Packages

CoDEC was undertaken as a project of 6 Work Packages:

- **WP0:** Project Co-ordination
- **WP1:** Develop Master Data Dictionary (MDD) for Legacy Data
- **WP2:** Develop Master Data Dictionary (MDD) for Sensor/Scanner Data
- **WP3:** Applied Research through Pilot Projects
- **WP4:** Software Industry Engagement
- **WP5:** Dissemination

Key Outcomes

CoDEC Data Dictionary

Review and Stakeholder Engagement

The development of the CoDEC Data Dictionary started with a literature review to understand the concept of data management within NRAs (in particular "legacy data" – i.e. data associated with existing asset definition/inventory and its status/condition and "new" data provided by surveys and sensors). This was complemented by an online survey, which was followed up via direct contact with individuals.

The review found that most NRAs have well-defined processes and existing systems for Asset Management. NRAs are also increasingly using sensors and other technologies for data collection and operational purposes. Many NRAs have also started using BIM during the design and build phase of projects because of the advantages it brings (more efficiency, better planning, better communication, etc.), and may also obtain digital representations of the result in the form of as-built BIM models. However, NRAs do not currently use BIM for long-term asset maintenance management.

The review also found that only some NRAs have developed data dictionaries (England, Lithuania, Norway, Sweden, Germany) and OTL (The Netherlands, Flanders, Finland) for specific projects on roads, bridges and tunnels.

As a further outcome of the stakeholder engagement three NRAs (Belgium, Finland and The Netherlands) were identified to work collaboratively as Implementation Partners for CoDEC in the development phase and to support the practical demonstrations in the Pilot Projects. All three NRAs provided consultation, information including OTL, asset data and 3D BIM models to help define the Data Dictionary Structure, CoDEC Ontology and the Pilot Projects.

Data Dictionary Structure and Content

The development of the Data Dictionary focused on the ultimate application to support the management of highway assets, which must include the management and reporting of both legacy (i.e. existing) data and new data, e.g. from sensors.

The development of the dictionary built on the previous work carried out in AM4INFRA (which developed a Data Dictionary for tunnels and bridges (AM4INFRA, 2018)), the Highways England UK-ADMM Data Dictionary (Highways England, 2020), the Data Standard for Road Management and Investment in Australia and New Zealand (DSRMI, for tunnels) (Austroads, 2019) and ifcRoad (buildingSMART, 2020).

These were combined with the experience and knowledge of the team in infrastructure asset management to identify the technical needs for: (1) what constitutes “an asset” vs the components of that asset, and (2) the level of detail needed to adequately describe that asset for the purposes of asset management. Hence a design for the Data Dictionary was proposed for three key highway assets (pavements, bridges and tunnels), including both the legacy data from these Assets and the data emerging from new technologies, such as sensors and scanning lasers. Having established the design, workshops were held in which the Data Dictionary content was presented and discussed with representatives from CEDR NRAs to validate the approach and the content.

Future Proofing the Data Dictionary

CoDEC had a particular objective to address sensors and the data they provide, as these are increasingly used to support infrastructure asset management. Sensors were not considered as ‘Assets’ in themselves, but rather as separate objects. The property sets which would apply in general to sensors were identified and included in the Dictionary. CoDEC considered it necessary to develop different property sets for sensors that have fixed locations and those that are mobile. This addresses differences in the approach taken to referencing the location of fixed and mobile sensors. In addition, there can be differences in how sensors are defined - for example, one can consider an array (or network) of multiple fixed-location sensors but this does not apply to mobile sensors. Therefore, CoDEC placed sensors in their own dedicated section of the Data Dictionary, separate from asset entities and elements. Figure 2 shows the content of the Data Dictionary for Roads and Bridges and Figure 3 shows the content for sensor data (these figures are truncated to fit, and as such do not show all fields). The Data Dictionary is published in a Microsoft Excel spreadsheet format so that it is easy to expand, and to include data from other assets.

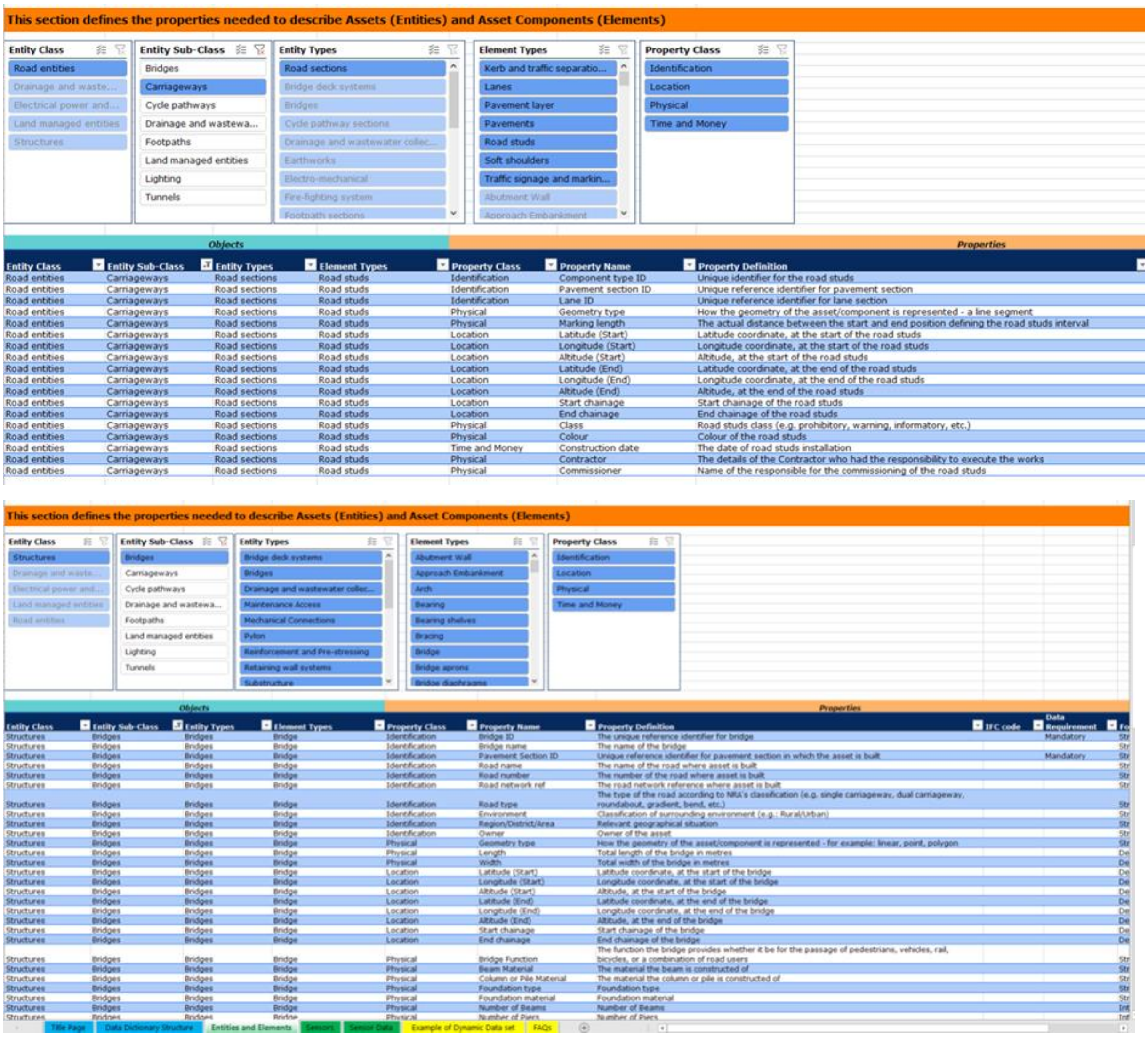


Figure 2: Data Dictionary showing Roads and Bridge Assets Data

Figure 3: Data Dictionary showing Sensor Data

Ontology, API and Architecture

Ontology

The CoDEC Ontology was built on the EUROTL1 framework (INTERLINK, 2018) using “Linked Data” and “Semantic Web” technologies. The Semantic Web helps link datasets so that they are understandable not only to humans but also to machines, and “Linked Data” makes these links possible. In other words, Linked Data is a set of design principles for sharing machine-readable interlinked data on the Web. The CoDEC Ontology was developed using the Resource Description Framework (RDF) Schema and the Ontology Web Language (OWL) which were developed by the World Wide Web Consortium (W3C).

As a first step, each Data dictionary entity was mapped to an existing class or property in EUROTL, as shown in Table 1. Properties are defined either as an object property or data property, meaning a semantic relation between object classes, or between the class and data (e.g. strings or numbers). CoDEC created a new class or property where mapping was not present in the EUROTL. The ontology was developed using Stanford’s Protégé (Musen, 2015).

As an example, the Bridge concept already exists in the EUROTL Framework (AM4INFRA 2018). However, the concept of a Structural Element (or equivalent) of the bridge is not found in EUROTL. Hence, a new Structural Element class was created in the CoDEC ontology, as a sub-class of the already existing EUROTL concept EurOTL:PhysicalObject.

Table 1: Example of Data Dictionary to ontology mapping

CoDEC Data Dictionary				CoDEC Ontology		
Property	**Description**	**Format**		**Domain**	**Object/Data Property**	**Range**
Bridge ID	The unique reference identifier for bridge	String		bridgeID	is-a	Bridge
Bridge name	The name of the bridge	String		bridgeID	rdfs:label	xsd:string
Environment	Classification of surrounding environment (e.g. Rural/Urban)	String	→	bridgeID	inEnvironment	xsd:string
Region/ District/Area	Relevant geographical situation	String		bridgeID	prov:atLocation	eurotl:LocationBy Identifier

Application Protocol Interface (CoDEC API)

The last step in the process to link data between different systems was to develop an Open Application Protocol Interface (CoDEC API). Application Programming Interfaces (APIs) are a “set of clearly defined methods of communication subroutine definitions, communication protocols” to support querying data to and from various sources using linked data/semantic web technology. By providing an API, CoDEC provides a practical and systematic approach that can be implemented by NRAs to connect their Asset Data with their BIM Platforms, and vice-versa. The concept of this API is shown in Figure 4.

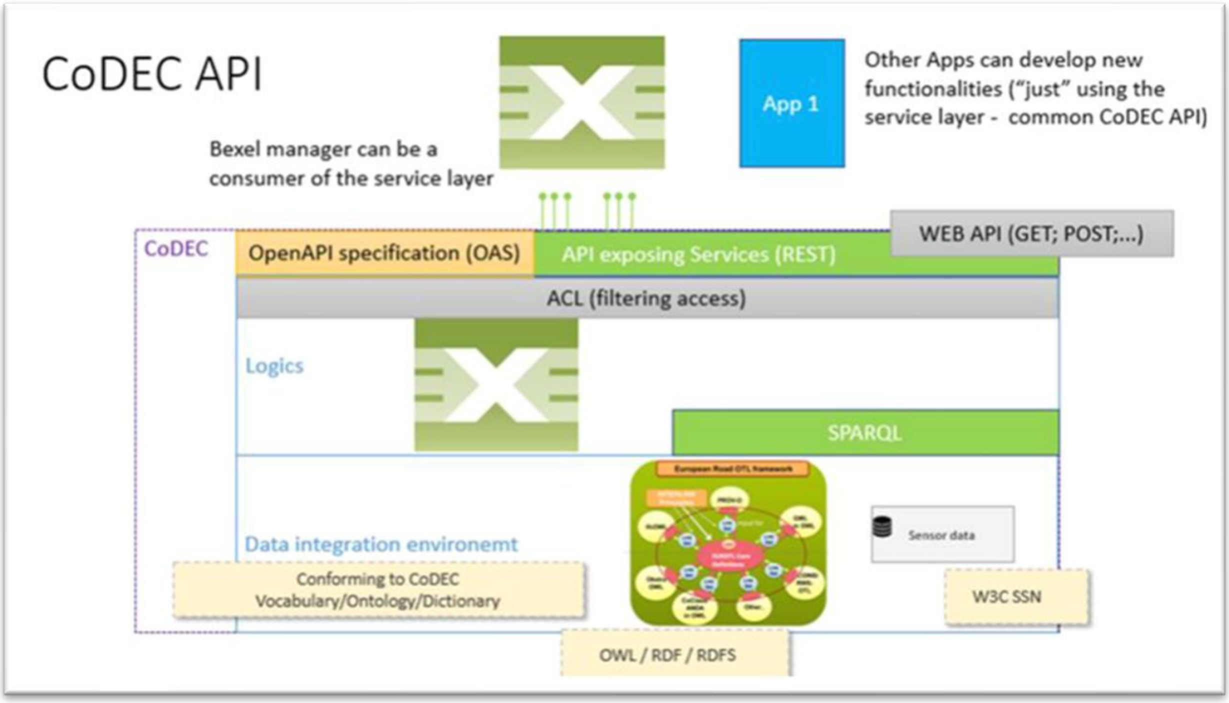


Figure 4: CoDEC API overview

The CoDEC API is a critical component of the technical solution. It creates:

- a layer of abstraction and independence between the data and logical levels,
- allows any technological solution to access the linked data environment,
- eliminates any technical dependency to access the linked data environment,
- allows the ontology to evolve without changing the applications that access it through the API and
- allows the complexity of the data to be isolated

The API can be used by any application without needing to know the details of the implementation for faster development and it simplifies the entire process of testing and validation. Finally, visualisation and data management tools allow access to the API to manipulate and access data in the linked data environment. For the end user, the only interface required with the CoDEC solution is the visualisation / data management tool, hiding all the complexity of the linked data environment.

Technical Architecture

To manage the complexity of the linked data environment and create a "separate layer" that can be used without interfering with other "layers", CoDEC employed a set of services (REST Web services and Python services). These services are responsible for communicating with the linked data environment, typically through a set of SPARQL queries and can be used by any application, as long as it has permission to access both services and data. This layered approach has several advantages, the most critical one being that the separation provided by multiple layers allows modification of the linked data structures without affecting the behaviour of external applications, as they just need to know how to call the services (their inputs and outputs). CoDEC delivered an

OpenAPI specification (i.e., description and documentation detailing how services can be called), ensuring this can be used by all NRAs. Figure 5 visualises the high-level architecture. The first layer highlights the existing information on which the technical solution was developed - namely, the Road OTL ontology of the Interlink project, making it possible to implement the CoDEC ontology from the Road OTL implementations, and the CoDEC Data Dictionary. The ontology instances are stored in a Linked Data Environment, so they can be accessed to meet the requirements of the different pilot projects.

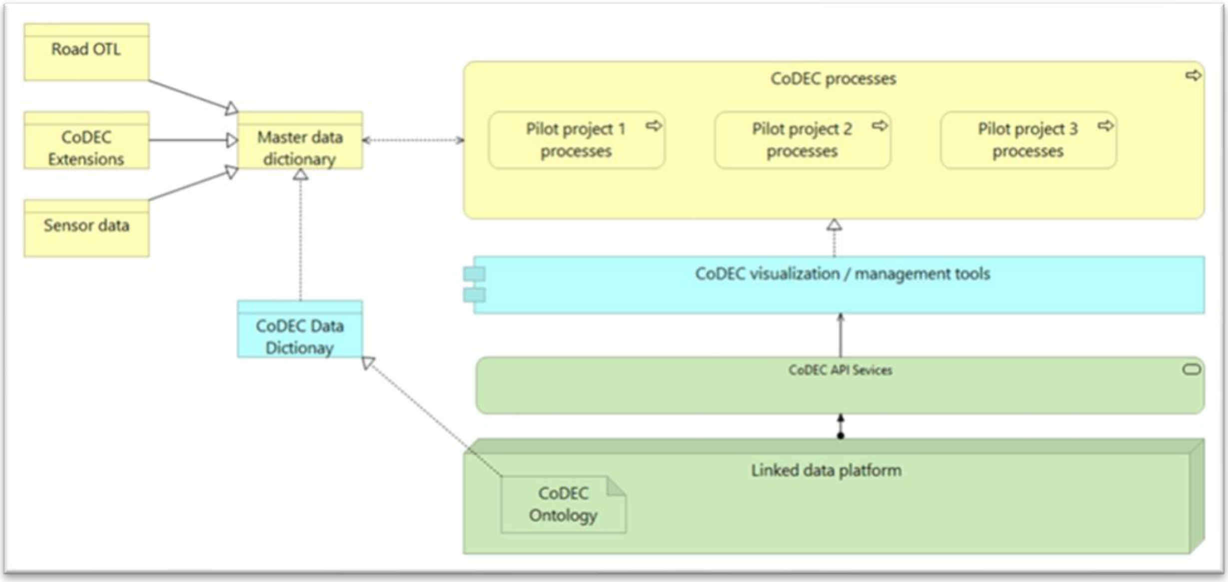


Figure 5: CoDEC Technical Architecture

Demonstrating the developed solution through Pilot Projects

As an initial proof-of-concept CoDEC developed a demonstrator using linked data from the INTERLINK project and a BIM model containing light posts. To implement this demonstration, CoDEC used Bexel Manager as the BIM environment. Following this proof of concept, the method was taken forward to the Pilot Projects. Three pilot projects were undertaken with three implementation partners (CEDR NRAs) covering three different asset types. The objectives of the pilot projects were to show that the CoDEC solution can be successfully implemented for different Asset Types and demonstrate how integration of different data sets in one system can improve and help NRA decision making. The three pilot projects were:

- Pilot Project 1: Integration and 3D visualisation of monitoring data within a BIM Model of a Tunnel
- Pilot Project 2: Linking and visualizing condition data with a Bridge BIM model
- Pilot Project 3: Enhancing legacy data by linking the BIM model of a Road to a GIS

Pilot project 1: Integration and 3D visualisation of monitoring data within a BIM Model

Pilot Project 1 was carried out with Agentschap Wegen & Verkeer (AWV), the Belgian (Flemish) NRA, using a BIM model provided by them. This Pilot Project demonstrated the use of the CoDEC approach to integrate sensor data within a Tunnel BIM Model. The model included a broad range of categories, families and element types for the Tunnel, and data was provided from monitoring sensors (CO, NO2, temperature, sight distance) installed in the tunnel (data collected over a period of one month).

A summary of how Pilot Project 1 applied the CoDEC approach is shown in Figure 6. The BIM model was imported to Bexel Manager and the sensor data was linked to the corresponding sensors in the 3D BIM model using the CoDEC Ontology and API. This mapping enabled an automatic, bi-directional relationship between the BIM elements and their related sensor data. The enriched BIM model can be exported using open standard formats such as IFC to other BIM applications that support open standards.

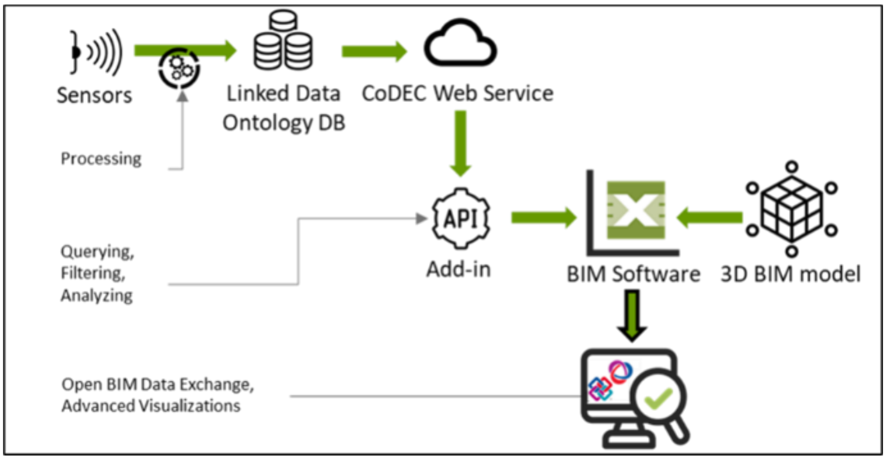


Figure 6: Methodology for Tunnel Pilot Project

Pilot Project 1 also considered the challenges of visualising distributed dynamic data within the BIM model – something that is not typically undertaken in BIM. Environmental sensors are themselves small elements of the tunnel located at point locations distributed along the length of the tunnel. The imported sensor cannot be shown in the BIM model just at the source point as it would not be informative. Hence, it was a challenge to find an ideal way to visualise imported data. In this case, the wall panel elements distributed along the tunnel were used to visualise the sensor values. Automating the sensor values to align with specific wall panels was one of the key workflows addressed in the pilot. Ultimately, sensor readings could be imported into the BIM environment and applied to specific 3D BIM model elements and wall panels to deliver visualisation of the environmental conditions. Figure 7 shows the 3D visualization of the sensor data in the BIM Model using Bexel Manager's 3D colour-coded view, with the sensors' values shown in different colours.

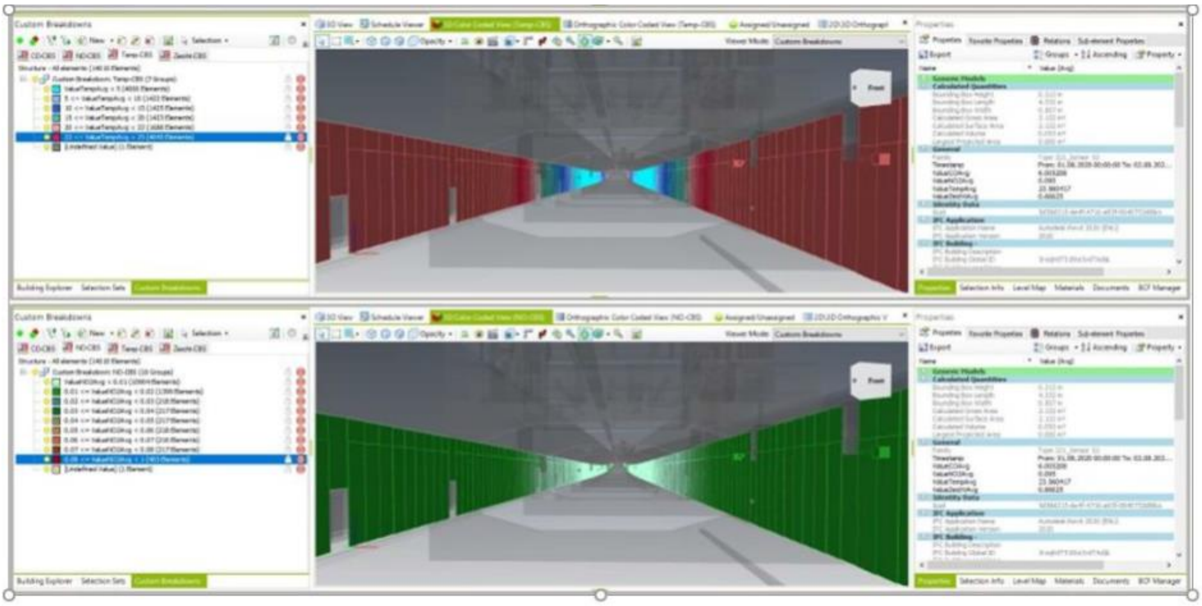
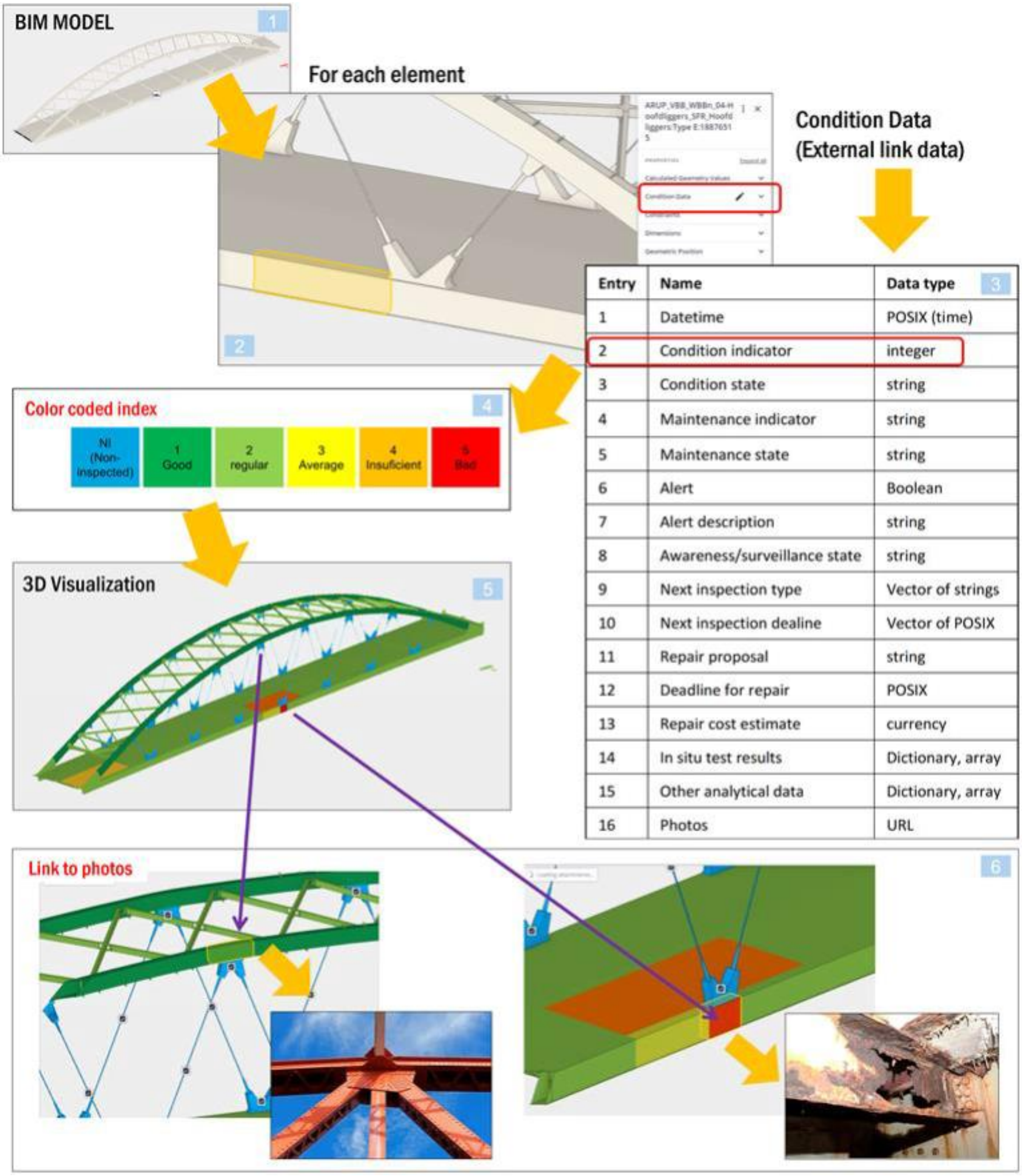


Figure 7: Visualisation of point sensor data in a BIM Model by colour coding wall panel elements of the tunnel

Pilot project 2: Linking and visualizing condition data with a Bridge BIM model

Pilot Project 2 was carried out in consultation with the Netherland NRA, who also provided the BIM model. This Pilot Project demonstrated the potential to use a BIM platform as a framework to store information and provide a visual interface that integrates condition data with bridge components in a BIM model. A summary of how the pilot applied the CoDEC approach is shown in Figure 8. The model, which was imported into Bexel Manager in IFC open BIM format, contained 496 elements of four different IFC Classes. A list of attributes was added to each BIM element to support association with condition data provided by inspections, including access to data such as photos.

Pilot Project 2 demonstrated visualisation and risk analysis of condition data directly in a BIM model by deploying the CoDEC approach. After opening the BIM model in Bexel Manager, all the typical functionality of the Bexel BIM tool was available. However, once the linked data add-in was installed, the user could also access the list of inspections associated with the structure and the risk and condition data associated with that inspection. Figure 9 shows the 3D visualisation of the condition indicator index that could be shown in the BIM Model (assigning different colours to the elements of the structure, according to the condition level determined for each element in the selected inspection). The same functionality was explored for other values associated with that inspection, namely, the qualitative assessment of the condition state of the elements, the deadline for the next inspection and the type of the next inspection.



Entry	Name	Data type
1	Datetime	POSIX (time)
2	Condition indicator	integer
3	Condition state	string
4	Maintenance indicator	string
5	Maintenance state	string
6	Alert	Boolean
7	Alert description	string
8	Awareness/surveillance state	string
9	Next inspection type	Vector of strings
10	Next inspection dealine	Vector of POSIX
11	Repair proposal	string
12	Deadline for repair	POSIX
13	Repair cost estimate	currency
14	In situ test results	Dictionary, array
15	Other analytical data	Dictionary, array
16	Photos	URL

Figure 8: Process of Connecting Sensor Data to Bridge BIM Model

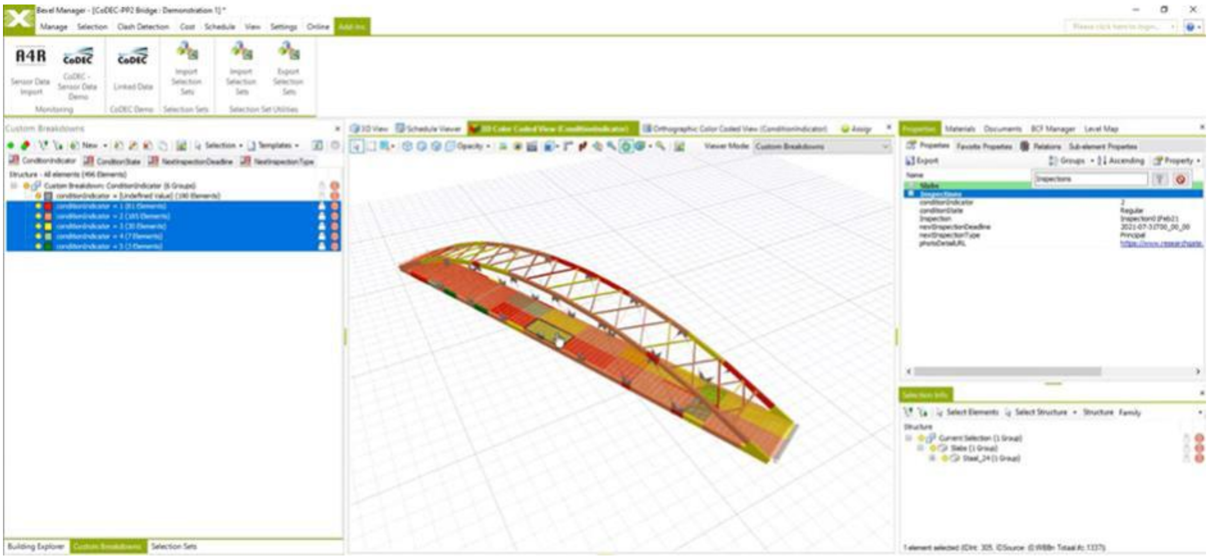


Figure 9: BIM Model showing coloured by condition indicator index

Pilot project 3: Enhancing legacy data by linking BIM models with GIS-based systems

Pilot Project 3 demonstrated that CoDEC methods can also be used to deliver data from BIM to other systems (whilst the opposite was demonstrated in the other two pilots). This Pilot was developed in consultation with FTIA (Finnish NRA). However, the data and BIM model was provided by the TRL Smart Mobility Living Lab, located in the London Borough of Greenwich, UK.

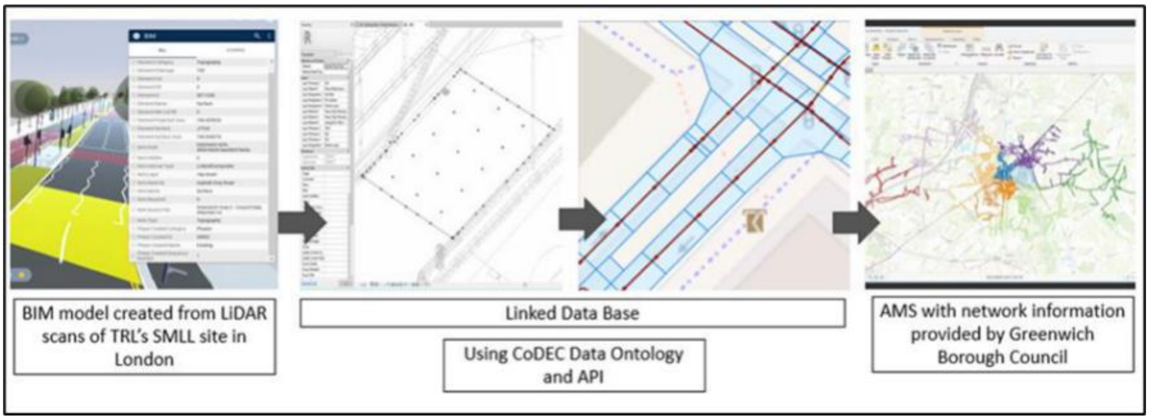


Figure 10: Linking data from the BIM model to GIS

BIM models are often created for the design/construct phase of Road assets, whilst roads are managed during the operational phase using GIS-based Asset Management Systems. Hence the BIM model often holds information useful for asset management, which could be used to enrich (and/or complement) the data held within AMS, However, this information is typically not made available to the AMS. Pilot Project 3 aimed to demonstrate this link. Figure 10 shows the process. The method of linking data from a BIM model to a GIS based AMS has three main elements:

1. Linking asset data from BIM to Linked Database
2. Linked Data Base to GIS and
3. GIS to Linked Data Base

Before asset data can be linked from the BIM model to the AMS, it is necessary to assign parameters from the detailed geometric representation in the 3D BIM model to the 2D line representation of the road network typically deployed in an AMS. 2D Network models are simple by design because they are used to provide insights on network performance as a quick and clear overview. Conversely, 3D BIM models provide a more detailed representation of the network. Converting these complex geometries to simple lines will result in loss of information. In the Pilot Project, CoDEC defined the pavement as a set of "slabs" (rectangular units) that together form the road network and intersected each of them with the lines defining the route of the road. The positions of the slabs were stored as linked data using the ISO 19148:2021 Linear Referencing ontology, used in the European Road OTL. This ontology provides a means to locate objects (assets) along elements of a network, alignments, or other linear elements. In this case the linear element was an individual slab within the road network. For each slab, the start and end position on the network was determined, by measuring the start and end distance relative to the start of the entire polyline, using tools in the ArcGIS system. Finally, these linear elements were uploaded back into the CoDEC repository using the CoDEC API. This approach enriched the road network model with information from the BIM model using linked data and international standards.

This Pilot Project demonstrated the use of the CoDEC ontology for successfully linking data between BIM and GIS, which could provide benefits including: Providing a single source of truth for highway assets; Having the required data available in the system where assets are primarily managed; and future-proofing such that data from new technologies (e.g. sensors, digital twins etc) can be supported within the AMS. The Pilot also provided experience in the practicality of applying the CoDEC approach and its implications for further implementation. For example, pavements are linear features but will need to be modelled in small segments in BIM to accommodate condition data (which may be associated with specific locations or parts (e.g., layers) of the pavement). There will be a need to determine the optimum size for such segments, and there are many factors influencing the decision – for example, the granularity of the data available to be attached to each segment, the road layout (curvature, length between junctions, complexity etc), and maybe even constraints on model size.

Conclusions and Recommendations

Data is vitally important to asset managers and supports decisions throughout the asset lifecycle. Although there has been progress integrating BIM into the operational phase of Assets, CoDEC was one of the first projects to consider this from the Asset Management side - creating practical methods to enrich data, data systems, and change our way of working.

Building on previous research projects, such as AM4INFRA and INTERLINK, CoDEC applied a methodical approach to develop a framework for data (the data dictionary) and translate this into a machine-readable framework (the ontology) to make AMS and BIM data interoperable. This provides a step on the journey to making data seamlessly available when and where it is needed across data management systems and supports the first steps in the transition from traditional Asset Management to operation via the Digital Twin.

CoDEC aimed to provide practical and implementable outcomes to NRAs that are also future-proof, by creating a framework that includes data provided by new technologies. Although, Codec did not cover all road infrastructure assets and data types, it provided a structured and practical framework that can be expanded to include other asset types and data as required in the future - hence catering for Road Authorities' future needs.

Although CODEC successfully developed applications to integrate data from different systems, there is substantial work still to be done in this area. One of key findings from the CoDEC Stakeholder engagement was that there is a lack of collaboration and common understanding of the data requirement across the stakeholders. The pilot projects have also helped to understand the limitations of current systems and identify the need for developments that could help the future exploitation of the CoDEC approach.

Based on the challenges and findings from this research, CoDEC recommended that:

- **Collaboration**: Collaboration between asset owners (such as NRAs), standardisation bodies (such as ISO and IFC) and the software technology industry should be encouraged, to understand the practical needs of asset managers/owners when it comes to data integration, and to build on the outcomes of this project to deliver the tools that will meet these needs.
- **Simplify level of detail within BIM models**: To simplify the discretisation of the visualisation components, it is recommended that BIM model designers develop elements with the appropriate level of detail for visualisation - i.e., that visualisation needs are considered when developing BIM models.
- **Normalisation and standardisation of conventions and nomenclature**: The mapping between the BIM elements and the elements present in the ontology is a critical aspect in the development of the integration. BIM solution manufacturers should provide advanced filtering mechanisms for generating ifcOWL from BIM models.
- **Automation**: Whilst the CoDEC solution is adequate, it requires effort in data instantiation and synchronization with distinct data sources that limits a fully automated method. Automating all steps in the process would increase the ability to exploit the results of the CoDEC project - allowing a real-time approach.

AMSfree – Exchange and exploitation of data from Asset Management Systems using vendor free format

Project facts

Duration: December 2019 – May 2022

Budget: 547 541.58 EUR

Coordinator: University of Applied Sciences (UAS Ka) (Germany)

Partners: Infrastructure Management Consultants GmbH (IMC) (Switzerland), INGEO (Netherlands), Ruhr-Universitaet Bochum (RUB) (Germany)

Website: http://www.amsfree.eu/

Project overview

AMSfree aimed to develop and implement approaches to combine asset management systems with BIM. This included concepts for exchanging linked data between Infrastructure asset management systems (IAMS) and BIM by using information containers. Furthermore, AMSfree aimed to develop a transformation concept for data exchange between information containers and legacy systems in different NRAs, via ontologies.

To achieve this the project analysed the architecture of Infrastructure Asset Management Systems used by NRAs, as well as the asset information content in current Asset Management Systems to establish the detailed technical requirements for linking IAMS and BIM. An analysis was performed on BIM models utilised by designers and contractors, so the level of development for a common infrastructure asset BIM could be agreed. To allow state-of-the-art data (e.g., from sensors and drones etc.) to also be incorporated, the requirements for existing condition assessment data were established and documented in an Information Delivery Manual (IDM) for the asset condition data. A generic IAMS-Process approach was then developed and an IAMS-oriented IDM was established. Proposals for extensions to existing IFC schema were developed and, for linking national data formats (e.g., OKSTRA), information containers according to ISO 21597 were used. Based on this, a prototype for linking legacy databases with IFC was developed, and tested using three different use cases for pavements and bridges.

Work Packages

The research approach conducted the following steps structured into **6 technical work packages**:

- **Comparative analysis of IAMS and common BIMs in Europe (WP 2):** A detailed analysis of the technical requirements for linking IAMS and BIM (as infrastructure databases) was conducted within this WP.
- **Digital Condition Assessment (WP 3)**: An overview of existing and current condition assessment techniques was established. An Information Delivery Manual for condition assessment was developed and the options for extensions to IFC examined.

- **Data fusion and semantic transformations (WP 4)**: The definition of an AM reference process model was established, building on the systems used by different NRAs. The process of data exchange, based on Information Containers for data exchange points in AMS, was described.
- **Development of a referenced vendor-free IFC based data structure (WP 5)**: Building on the Information Container, an IAMS-oriented Information Delivery Manual was established, and a guide for linking European Road OTL and national Classifications.
- **Data Exchange to legacy Systems (WP 6)**: A prototype was developed and architecture for IFC property mapping as described.
- **Development of a Prototype (WP 7)**: In the final WP the process was tested via example use cases connected with the typical tasks of an IAMS.

In addition to the technical work packages, **WP 1** was dedicated to the project management aspects of the project.

Key Outcomes

Information Delivery Manual (IDM) for condition assessment

A major challenge when setting up a process for data exchange for importing results, into traditional as well as BIM-extended asset management systems, is to determine the level of detail. The Information Delivery Manual (IDM) in AMSfree project focused on the exchange of the results of condition assessment and condition evaluation between road or bridge operators and the inspecting organisation. The IDM enables the information scope to be specified for the handover to the inspector and for the data delivered to the operators. A process map was created to describe the data exchange of condition data to/from IAMS/BIM, as shown in Figure 11.

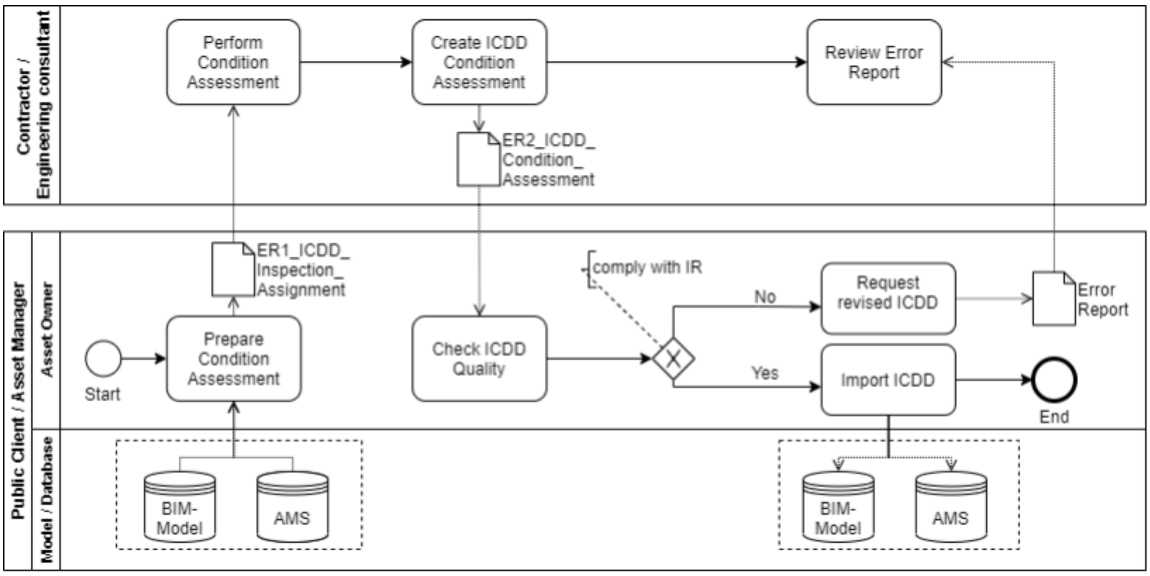


Figure 11: Generic process map for condition assessment data exchange

There are two main data exchange points. The first data exchange point describes the transfer of information required to perform inspections (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 exchanged data is prepared as a whole package using Information Container for linked Document Delivery (ICDD) according to ISO 21597, and discussed further in the next section. The individual processes and data objects are:

- Prepare Condition Assessment: Information necessary for the condition assessment is compiled in an information container as a template and transferred to the assigned persons. It includes the specification, which characteristics are to be captured, and how the raw data and results are linked to the BIM model.
- Perform Condition Assessment: The condition assessment is carried out without consideration of the internal processes of the inspecting organization.
- Create ICDD Condition Assessment: The captured and interpreted data is prepared on the basis of the information requirements. Templates are used to document the information by the inspecting organization. The completed results collected in the ICDD are delivered to the operators.
- Check ICDD Quality: The information container is validated vis a formal technical examination. The technical validation requires comprehensive experience and can be supported by suitable visual representations. The formal validation includes checking compliance with the information requirements, e.g., checking the link types defined in the container conforms to the link types specified in this document.
- Import ICDD Condition Assessment: The valid condition assessments, including the underlying data, are then integrated back into the asset management systems and linked BIM data environments.

Information Container for linked Document Delivery (ICDD)

The Information Container for linked Document Delivery (ICDD, ISO 21597) has been developed in response to a need within the construction industry to handle multiple interrelated documents via 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:

- 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. This folder can have subfolders for storing further documents.
- A payload triples folder is used to store all links as one or more “Linkset files”, and may have sub-folders.

Different relationships (or link types) can be used to add information on the contents of a container, rather than extending the contents. The defined link types provide the ability to state comparison, ordering, and dependency relationships between the documents and entities within documents that form part of the payload of a container. These contribute 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, but without making any assumptions about, or being dependent on, the specific type of the link elements. This allows the container to be both machine readable and interpretable by humans.

The exchange requirement models (ERM) are hence defined for the two data exchange points identified in the above process. The first ERM is created and delivered by the road operator. The contractor creates the second model and delivers it back to the client. It should contain all the inspection results and the links to the BIM model.

ICDD Content for Condition Assessment

Three different technologies of condition assessment were considered for bridges and roads:

- Visual inspection of bridges
- Dynamic response analysis of bridges
- Ground penetrating radar on roads

The ICDD content must be specified and described for the data exchange. The information containers differ according to the ontologies, links, and documents that will be used and stored. The container for the three use cases must be determined or modified in accordance with the user specification.

Visual inspection of bridges. A visual inspection of a bridge is carried out on all important components, with all damage documented (textually and visually using photographs) based on a given template. A report is created for each inspected component. The corresponding structure of the two information containers is shown in Figure 12. The left table shows the Exchange Requirement (ER) model for the inspection and the right table shows the Exchange Requirements (ER) for the reported condition assessment (the results).

Requirement Container		
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
	ExtendedLinkset.rdf	rdf
	ExtendedDocument.rdf	rdf
	DamageClassification.ttl	rdf / ttl
	ConditionClassification.ttl	rdf / ttl
	BridgeClassification.ttl	rdf / ttl
Payload Dcuments:		
	BridgeModel.ifc	ifc
	ReportTemplate.xsd	xsd
Payload triples:		
	ifc2BridgeInstanc.rdf	rdf
	instanc4BridgeClassification.ttl	ttl

Result Container		
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
	ExtendedLinkset.rdf	rdf
	ExtendedDocument.rdf	rdf
	DamageClassification.rdf	rdf / ttl
	ConditionClassification.rdf	rdf / ttl
	BridgeClassification.rdf	rdf / ttl
Payload Dcuments:		
	BridgeModel.ifc	ifc
	LocalPlacement.ifc	ifc
	Report.xml	xml
	ImageDamage.png	jpg/png/gif
Payload triples:		
	ifc2BridgeInstanc.rdf	rdf
	instanc4BridgeClassification.ttl	ttl
	DamagePlacement.rdf	rdf
	ReportLinking.rdf	rdf
	ReportVisualDetails.rdf	rdf

Figure 12: Structure of information containers for the visual inspection of bridges

Dynamic response analysis of bridges. To measure the dynamic response of a bridge to load, a fixed mounted sensor can be used to measure the acceleration of the bridge when a vehicle is crossing. Numerical analysis of the sensor data can detect frequency shifts that indicate, for example, the development of scour around the bridge foundation. For this condition assessment, information such as sensor measurement data and the scour analysis at the foundation are returned as the results. The corresponding structure of the two information containers is shown in Figure 13.

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
	ExtendedLinkset.rdf	rdf
	ExtendedDocument.rdf	rdf
Payload Dcuments:		
	BridgeSensorModel.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
	ExtendedLinkset.rdf	rdf
	ExtendedDocument.rdf	rdf
Payload Documents:		
	BridgeSensorModel.ifc	ifc
	SensorData.xml	xml
	Report.xml	xml
Payload Triples:		
	SensorLinking.rdf	rdf
	ReportLinking.rdf	rdf

Figure 13: Structure of information containers for dynamic response analysis for bridges

Ground penetrating radar on roads. Ground Penetrating Radar (GPR) can be used to detect voids within the pavement and to measure the thickness of the pavement layers. GPR surveys can create large amounts of raw data which do not themselves provide direct results. Instead, further specialist processing is carried out. The raw data are therefore generally stored and managed in a central repository and the evaluation of the road condition (e.g., layer thickness, and defects) is reported to asset managers. To meet this requirement, the two containers are created, as shown in Figure 14.

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
	ExtendedLinkset.rdf	rdf
	ExtendedDocument.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
	ExtendedLinkset.rdf	rdf
	ExtendedDocument.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 14: Structure of information containers for ground penetrating radar analysis for roads

Reference architecture for BIM-based asset management

For asset management of bridges and roads, different data sources have to be merged and evaluated. Various approaches and systems have been developed in different countries to achieve this. In many cases, individual databases and interfaces have been developed for specific applications. Geographical information systems (GIS) have essentially been used for the geographical location and description of surfaces (e.g., for road management). However, with the introduction of BIM, three-dimensional information is now available and BIM models provide new possibilities for the planning, construction and operation of bridges and roads.

AMSfree followed the approach of using existing legacy systems for BIM-based asset management, using the concept of Linked Data. Linked Data means that no data is copied between systems. Instead, the data is accessed directly from the individual data sources for the asset management processes via standardised queries. The approach is used in ISO 21597 to exchange data using information containers. The AMSfree proposed reference architecture for BIM-based asset management consisted of a total of five layers (cf. Figure 15):

- **Data layer**: This is within the existing legacy systems used for asset management. It is essential that only one source is responsible for managing the data required for the management of the asset. If information must be stored in two databases, the system ultimately responsible for the management must be clearly identifiable.
- **Access layer**: Each legacy system must be able to access the data. Different access options usually exist for the different systems. A user login is usually required for access. A system should also provide the capability for “single sign-on”. With single sign-on the user can access all services for which they are authorised from the same workstation after a one-time authentication.
- **Ontology layer**: Access to the data is provided using the Resource Description Framework (RDF). To achieve this the data models in the legacy systems must be modelled using RDF. In general, RDF provides standardisations for the vocabulary used to characterise ontologies. To prevent the ontologies and RDF description becoming too complex, only relevant information from the underlying systems should be modelled. If all systems are mapped in this way, standardised query languages (e.g., SPARQL) can be used to access the data. SPARQL is an RDF query language to retrieve and manipulate data stored in RDF format. The ontology layer must be implemented and available for each data source or system.
- **Linking layer**: A linking layer can be built to link the different data sources using the RDF approach. The link layer is also implemented using RDF. Similar concepts are also provided in ISO 21597. In addition, higher-level ontologies can be defined that allow terms to be merged even though they have different names or identifiers in the individual systems. Uniform queries can be realised across all data sources through the linkage and the additional ontologies. This approach is also the basis of the Semantic Web and has already been successfully implemented for other applications. In addition to SPARQL, GeoSPARQL can also be used to enable geographic queries. GeoSPARQL is a standard for representing and querying geospatial linked data for the Semantic Web from the Open Geospatial Consortium (OGC). The definition of a small ontology based on well-understood OGC standards is intended to provide a standardised exchange basis for geospatial RDF data which can support qualitative and quantitative spatial reasoning and querying with the SPARQL database query

language. The linking layer should be operated centrally by the respective national authorities.

- **Application layer**: The application layer is applied for the higher-level use of the data. Services for importing and exporting data as well as options for analysing and visualizing data are implemented. For this purpose, individual queries or update commands are implemented on the basis of SPARQL. The standardized visualisation of geometric data can be a significant challenge. For geometric queries, various concepts have been developed in recent years for the IFC data format and other GIS-based data formats. In AMSfree a rudimentary examination was made with regard to geometric queries, as the project's key focus was on importing, exporting, and retrieving information for bridge and road asset management.

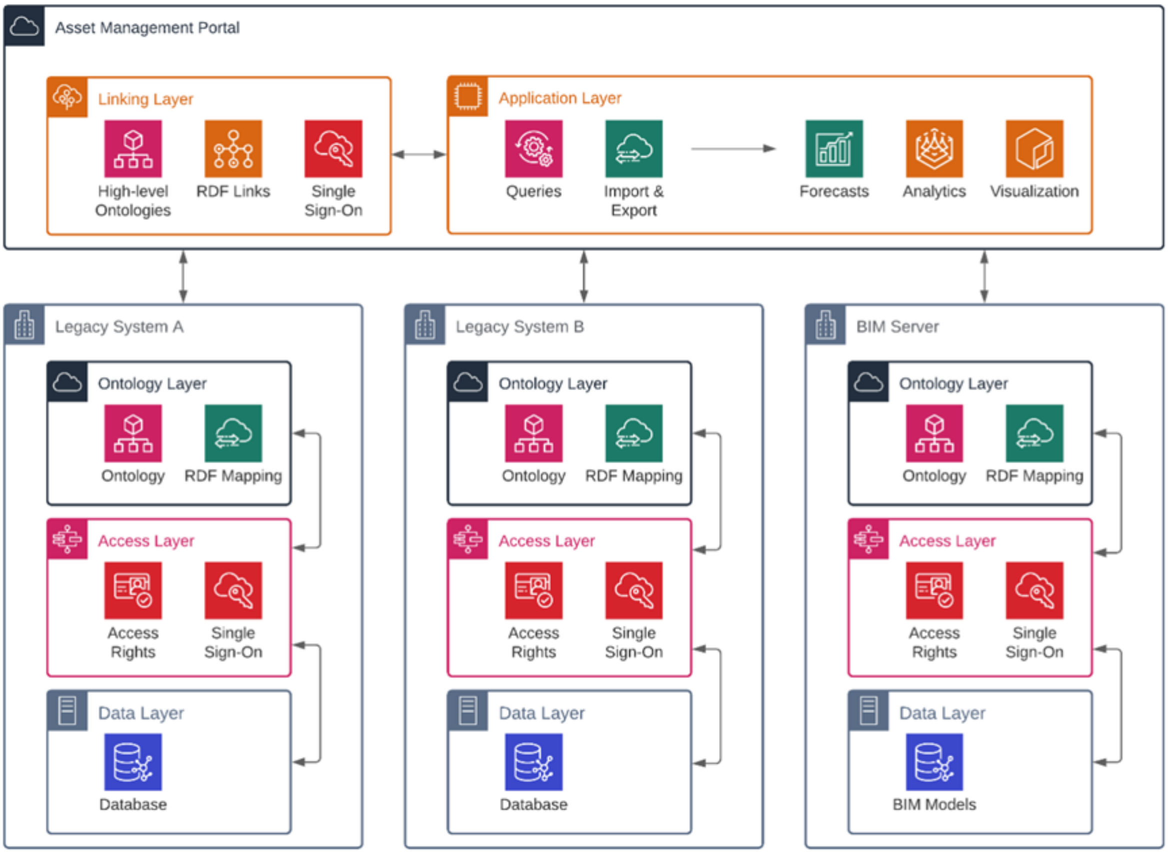


Figure 15: Reference architecture for BIM-based asset management

A referenced vendor-free IFC-based data structure

IAMS-oriented Information Delivery Manual (IDM)

Information Containers enable the establishment of information transfer between BIM and IAMS. For the information from the Information Container for linked Document Delivery (ICDD) to be fully accessed, an information exchange between BIM and ICDD (on one hand) and between ICDD and IAMS (on the other) needs to be enabled. Whereas the former is enabled by the providing the resource ontologies, the latter is established by means of the Information Delivery Manual

(IDM) for 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)).

We have discussed the use-case of condition assessment to show the scope of the information exchange between ICDD and IAMS above (Figure 11). The focus here is on the information flow between ICDD and the AMS database by the activities “Prepare Condition Assessment” and “Import ICDD Condition Assessment” defined in the process map. This information flow can be applied for maintenance use cases for both roads and structural assets (Figure 16). On the left-hand side is the ICDD (whose content depends on the use case). On the right-hand side is the Infrastructure Asset Management database. In between, we show the sub-process of data transfer between ICDD and IAMS. AMSfree proposed a process model for this that relies on the approach described by (Liu, Hagedorn, & König, 2021), with data transfer utilising the information transformation schemas proposed by (Costa & Sicilia, 2020) and the ontology mapped to the IAMS database following the approach of (Afzal, Waqas, & Naz, 2016). All the activities, including the data exchange, are done automatically. Firstly, the rules for mapping the ontology entities to the database are defined. Here, the ontology type may refer to the multiple object instances in the BIM model, and thus need to be mapped to multiple database entities. (Costa & Sicilia, 2020) labelled such mapping scenarios as “many to many attributes”. Once the mapping rules are defined, the SQL script targeting the correct database entities are generated. This is done by means of SPARQL-Construct queries. Finally, the SQL script imports the ICDD data to the IAMS. A thorough specification of this process model is shown in Figure 17.

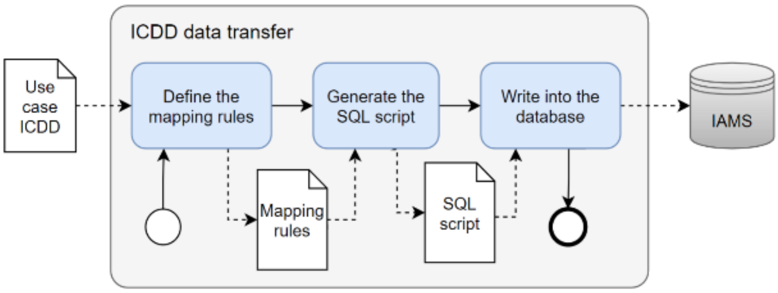


Figure 16: Process model for transferring data from ICDD to the IAMS database (BPMN)

Process Model			
Name:	PM_ICDD-IAMS_data_transfer		
Identifier:			
Authors:			
Create Date:			
Document Owner:			
Task	Name		Description of Task
	Define the mapping rules		Pairing of ontology types from ICDD with corresponding IAMS database entries
	Generate the SQL script		Automatic generation of the code for the SPARQL-Construct query which singles out the entities to be written into the IAMS database
	Write into the database		Automatic fill of the IAMS database table with the selected data from the ICDD
Exchange Requirements	Name	Type	Description of documentation
	Use case ICDD	ICDD	Information Container for linked Documentation Delivery whose content depends on the use case.
Object Data	Name	Type	Description of Object Data
	IAMS		Infrastructure Asset Management System

Figure 17: Process model for transferring data from ICDD to the IAMS database (table specification)

IAMS-oriented Application and Extension of the IFC Standard

AMSfree proposed ontologies for the information containers for bridge inspection and pavement maintenance planning (in terms of content and linkage between different data sources) according to the national guidelines and standards of three of the project funding countries (Germany, Netherlands and Denmark). The Model View Definition (MVD) for the IFC model was created for the defined use cases. Using ontologies, the semantic information of the inspection and maintenance plan could be captured as rdf-based data in the information container.

The IFC model provides the geometry in sufficient granularity of the structure and the pavement. However, it is possible to add semantic information directly to the IFC schema as properties. If property sets are added directly to the IFC, appropriate software must be available and attention must be paid to ensure that fundamental structures are not changed during the IFC export. When exchanging models via IFC, the exchange requirements of the defined use case must be complied with. These can be defined as rules using the MVD. This provides a technical solution to capture the use case specific rules in a machine-readable format mvdXML (Borrmann, König, Koch, & Beetz, 2015). The user can define their own MVD on the specific requirement as mvdXML. Although the mvdXML can be defined using any text editor, a free tool IFCDOC.EXE (IfcDoc Tooltik, 2021) provided by the bSI can be used for generation of user-defined mvdXML. The mvdXML must contain two constituents: templates and views. Templates provide reusable concept as templates, which include the applicable schema, the applicable entity, the rules with attribute definitions. The view contains a set of model views, which include the exchange requirements and the referenced concept.

Based on the defined property sets for the pavement and asset management activities, three Model View Definition, MVD, examples were defined:

- MVD handover for operation with drillcore properties
- MVD bridge inspection with condition assessment properties
- MVD maintenance plan with measurement properties

Linking Guide to the OTL

A European road object library (EUROTL) of ontologies were developed in the INTERLINK project for gathering and exchanging the asset information. This ontology provides a set of classes, which support the basic information needs for asset management. AMSfree followed the recommendations of INTERLINK.

In general, an ontology can be defined by the languages RDFs, OWL and SHACL which provide classes, data, their relationships, and restriction types that can be used to define attributes, objects and constraints. INTERLINK suggested that the ontology should be modelled in "The Simple Way", which means that OWL and SHACL are combined. The value attributes can generally be modelled as owl:DatatypeProperty's, and the relationship as owl:ObjectProperty's. Although the constraints can be modeled as OWL constraints. Class, property and data type names should be human readable. To improve readability for classes, properties, and data types, additional annotations can be added using rdfs:label. The rdfs:comment can be used for the description.

In the case of decentralised data, ontologies and datasets are usually created, edited, and stored by different parties. RDF, OWL and SHACL provide specific vocabularies that can be used to define the links between data. To mark two things as the same, owl:sameAs can be used, as suggested by INTERLINK. It also introduces three levels of linkage:

- Class-level linking means how to map classes and properties in different ontologies.
- Model-level linking means how to relate the different models to each other
- Instance-level linking means how to relate the instances or objects to each other

The linking data sets on the instance-level can be realized by the information container according to (ISO 21597-1, 2020). The linking Ontology for the class-level can be realised by creating an alignment ontology. The predefined ontologies for bridge and road condition assessment, and maintenance programs for pavements can then be linked to EUROTL using alignment ontologies as shown in Table 2.

Table 2: Overview of alignment ontologies for the predefined inspection and maintenance ontologies linking with EUROTL

Prefix	Namespace	Description	Illustration
CODEX2EUROTL	<http://www.roadotl.eu/codex2eurotl >	Linking between bridge damage ontology cod, codex and the eurotl	Figure 13-a
COAS2EUROTL	<http://www.amsfree.eu/ontology/ coas2eurotl/>	Linking between ontology of condition assessment and eurotl	Figure 13-b
MAINTP2EUROTL	<http://www.roadotl.eu/maintp2eurotl/def/>	Linking between ontology maintenance program and eurotl	Figure 13-c

Data Exchange to Legacy Systems using information containers

Guideline IFC Property Mapping

AMSfree provided guidelines to provide potential NRA users of Building Information Modelling assistance in the implementation of the approaches developed in the project to use information containers to exchange linked data between IAMS and BIM. The guidelines included a description of the proposed approach, including use cases, the software and data/file formats used as well as an illustrative application of the developed concepts on the example of a road section and a bridge. They gave a detailed explanation on how to proceed as a user in updating the AMS database to mirror physical reality.

BIM Creation Workflow and Software Tools

The data exchange and links between BIM models and IAMS is facilitated using the IFC file format developed by buildingSMART international (bSI), which provides 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 (IFC4 ADD2 TC1 (ISO 16739-1:2018) and IFC2x3 TC1 (ISO 16739:2005)) mainly define building-related concepts but activities to extend the official schemas are underway. Geometry-based, the proposed approach is applicable to any IFC file, regardless of the schema version. The asset management information flowing between IAMS and BIM is mainly provided by the information container, not the IFC semantics. The exception is the condition assessment data conveniently 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, and hence do not affect the BIM handover requirements.

The BIM modelling approach should be selected based on the type of the model to be created. The following three cases were considered in AMSfree: as-designed; as-built; and as-is BIM modelling.

- BIMs are usually produced in the design stage and updated later due to changes during construction phase. The final version of should reflect the asset at the moment of commissioning. This is called “as-built BIM”.
- The typical environment in the construction industry is such that the final BIM usually corresponds to a particular late design or construction phase. This type of BIM is called “as-designed BIM”, which will probably that handed over to the IAMS.
- Whilst the above refer to the starting point of the asset’s life (whether in the design or in the construction phase), “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 model, and requires either inspection data or the design documentation of the maintenance works.

In the context of Building information modelling (BIM) software AMSfree considered authoring software, coordination software and Common Data Environments.

- Many BIM authoring software tools are available, most of the which can export IFC 4.1. However, IFC 4.1 does not offer a satisfactory solution for the alignment of roads.
- 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, which can combine this data into a single, comprehensive, multidisciplinary model, that can identify the potential collisions (clashes) across these different sources.
- The Common Data Environment (CDE) provides 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. Again, there are numerous tools available to support this.

Ontology Creation

Beside the IFC model, semantic information can also be digitalized and stored as instances using ontology. Ontologies are used to provide data schemas described by a document or a file that formally defines the relationships between 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. An Web Ontology Language (OWL) ontology was developed during the AMSfree project according to the needs of the asset owner. AMSfree’s focus was mainly to use an existing ontology (for instance, EUROTL for Infrastructure developed by INTERLINK). Regardless of the computer languages in which they are expressed an ontology formally organizes the domain under consideration by defining concepts and relations between them. The domain ontology used by an asset owner must describe 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 the ontology in any form - even purely textual. In AMSfree “TopBraid Composer” was used to author classes and properties of a domain ontology. Once the ontology is defined, the instances of ontology class and property can also be created 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 RDF format. The links between the cross-ontology instances can be created within the information container.

An example for a pavement condition survey is shown in Figure 18. The EUROTL framework provided core definitions which cover basis classes considering the infrastructure asset life span. These core definitions could be extended or linked to further existing domain ontologies (e.g. OKSTRA OWL, IFC OWL). The pavement condition survey data can then be collected as instances of the ontology. The main parts of the survey data are: the activity; road section; the condition of the section. The instances of each can be created by the EUROTL classes: the activity as an instance of class “InspectionActivity”; the road section as an instance of class “Lane” and the condition of the section as an 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 road section using the available properties. However, if the existing ontology does not cover the whole information requirement, extensions of the ontology can be created if necessary.

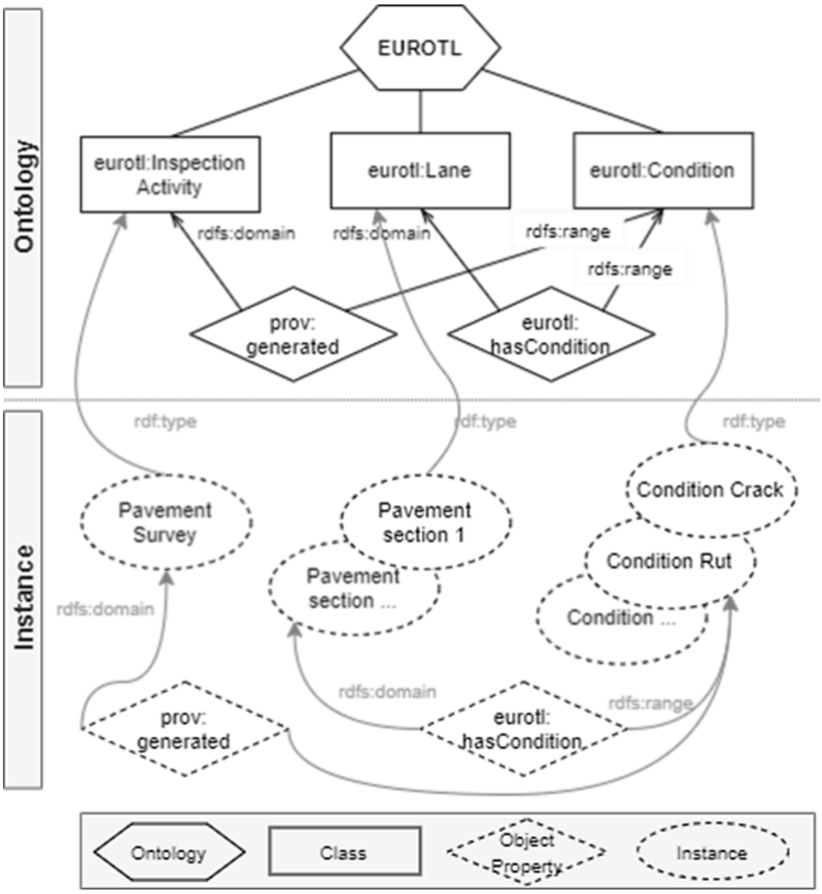


Figure 18: Example for instances of EUROTL ontology

Information Container Overview

ISO21597 was developed in response to the need of the construction industry to handle multiple documents within one information delivery or “data drop”. The 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.

AMSfree develop a concept for the definition of information containers for data exchange with legacy IAMS. Existing national data formats (e. g., OKSTRA) were linked with the IFC format. Which data is transported via which format (e.g., IFC, OKSTRA) was documented, along with which data is mapped to each other and how, and which, consistency checks are necessary. A framework developed by RUB was used for the creation of information containers according to ISO21597,

As the information containers were defined based on ISO21597 they can be used or extended easily and without restrictions. The information container specifications were made available in neutral IDD format on the project website, without restrictions to CEDR members and the market. The information containers can be used when there is a national need for more information and to interact with existing legacy systems. This is a practical approach that allows the re-use 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. Information Container for linked Document Delivery (ICDD, ISO21597) is the data structure intended for handling a variety of interrelated documents. The documents in the container are contextualised, 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).

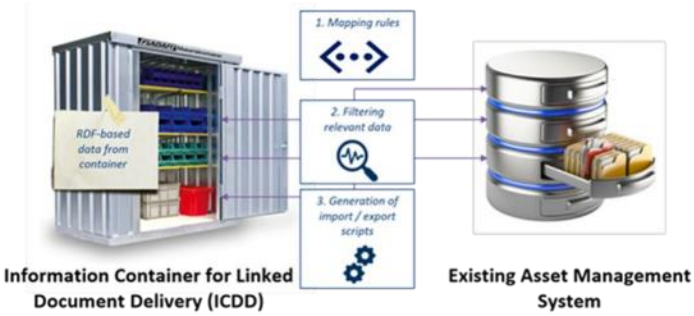


Figure 19: Graphical representation of the data exchange between ICDD and AMS database

IFC Property Mapping examples

In AMSfree the functionality of the IFC property mapping was tested using two examples. An IFC model of a bridge and a section of pavement were created and enriched with property sets. Since not all properties were available in the IFC, the properties were extended to link further data within the model. The extended property sets were defined for the condition information, and could be linked to the corresponding pavement segment and layers of a road via an ontology authored for this purpose. The external file with the condition information was only linked to the model, and not directly integrated. The extended property sets defined and listed in AMSfree project are available for download at http://data.amsfree.eu/ (*Login: AMSFree, password: CEDRCall2018!*).

Bridge IFC Model

The bridge model used, as an example, a BIM of a 12.5m supported double girder bridge built in the 1930s. The bridge was modelled using Autodesk Revit. The model complies with the LOD 350. Girders, railings, roadsides, and asphalt cover were modelled as in-place structural framing components. The model was exported in IFC format. Figure 20 shows the model of the bridge.

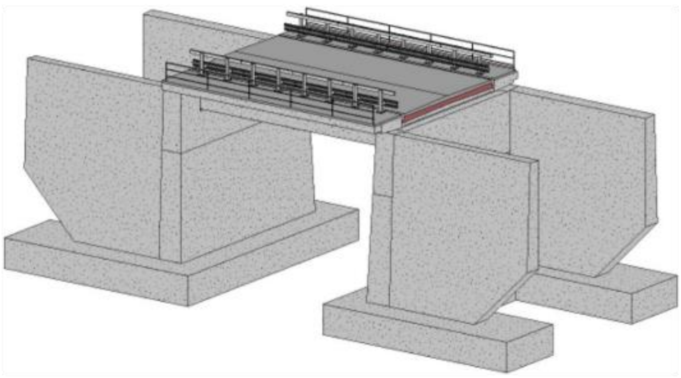


Figure 20: BIM model of a bridge (Isailović 2020 as cited in Stöckner *et al.* 2022)

Road IFC Model

The IFC example model of a road pavement was a 1km long straight section (Figure 21). This was split into two 500m long construction sections. Furthermore, the section is divided into ten 100m 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 condition data and measures on the corresponding sections. The model was created with the AutoCAD extension ProVI and exported to IFC format.

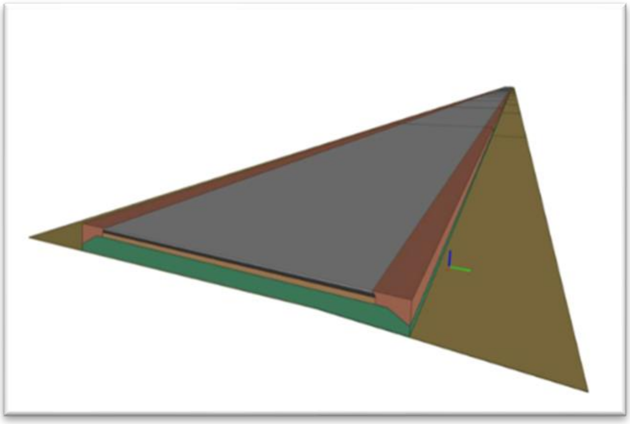


Figure 21: BIM model of a road section

Prototype

Functional memorandum for software engineers

A prototype was used to demonstrate that the IAMS data can be shown in a BIM viewer and that changes can be synchronized within both data sources. The format of BIM files used by the prototype application was IFC.

The ICDD data structure was used to handle the interrelated documents. The documents in the container were organized, and the data linked according to, the ICDD specification. All the information stored in the container was contextualized by means of ontologies, also the part of a container. A web-based ICDD-Platform was developed for the realisation of the ICDD, which provided functionality to create projects and information containers and the functionality to edit, modify and delete containers and container content. The system architecture of the prototype developed to realise the ICDD-functions can be described in 3 components, as shown in Figure 22. The created containers are recorded in the data repository. The business & data access logic component provides the core processors for the functionality of the ICDD, and management of the data flow from the data repository to the presentation component. The Container Processor provides tools to create, edit and delete the container content. Other sub-processors related to the Container Processor can retrieve or send container-related data (IFC Processor processes IFC-based building models; SPARQL and SHACL processors retrieve and validate data from the container;R2RML Processor realises the data integration from the external database into ICDD using predefined mapping rules). The Web User Interface provides an interface for presenting and interacting with the business & data access logic component.

Additionally, through the IFC viewer it is possible to create queries related to selected IFC objects in the container without much SPARQL knowledge.

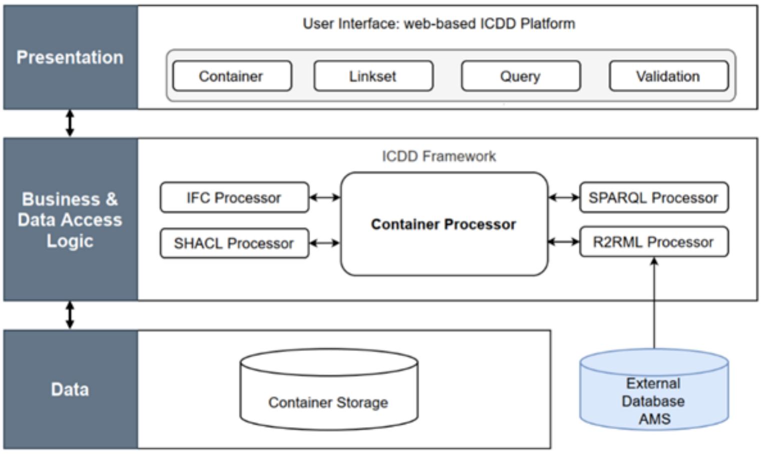


Figure 22: System architecture of the prototype ICDD-Platform – core functionalities with ICDD

Web Application

The AMSfree prototype could be used to link IFC models and AMS. Containers could be uploaded to the Information Container Data Delivery (ICDD) Platform and extended or completely created in it. Users could then use the containers to link information in the prototype and create relationships. In addition, IFC models could be displayed in the IFC viewer, which could be clicked on to retrieve information. The prototype could be used to synchronise changes in the AMS and the BIM database.

The intended application of the AMSfree prototype was for the AMS life cycle of roads and bridges. This includes project creation, condition assessment, maintenance planning and as-built models of implemented measures.

The developed web application can be accessed using the following URL: https://icdd.vm.rub.de/amsfree/ (*Login: AMSfree, password: CEDRCall2018!*).

Mapping Software Architecture

A mapping tool can be developed to create customised property sets as templates, and to add the defined property sets to the entities of the IFC model. This would need to consider software architecture shown in Figure 23. The tool would need to contain three major components to the create and map properties within IFC schema:

- **Templating: generate the property set template** Templating includes three functions. The user could create property set templates with a human readable form provided by the user interface. The input data for the property set would be converted into IFC schema. The generated property set templates could 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 could be added to the IFC model object. In the same way, the user could import the property set templates in the supported datatype and add them to the IFC model. 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**: To view the geometry and interact with IFC model via the 3D Viewer.

- **Model Content:** To view the structure and properties of the IFC model and select the IFC object. There are various visualisation tools, e.g., Xbim-Toolkit (https://docs.xbim.net/) which enable integration of the 3D viewer into a self-developed system. AMSfree preferred to use the IFC Apstex Toolbox Framework.

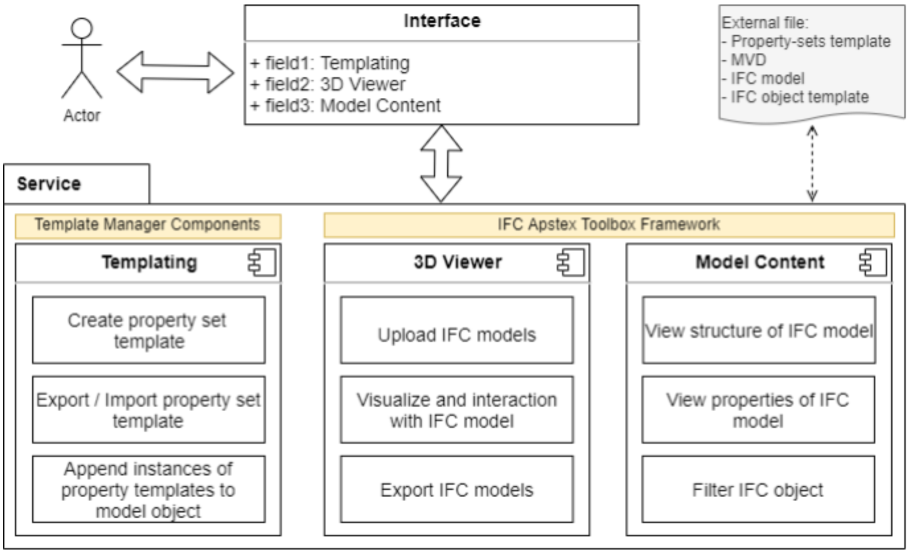


Figure 23: System Architecture of a Mapping Tool for the IFC Property Template

Conclusions and Recommendations

In AMSfree a prototype was developed to evaluate the concept of sharing, exchanging and visualisation of data between asset managers and external contractors using Information Containers. The ICDD provides an environment for capturing and linking data in different formats. File-based documents can be linked in this Information Container. In summary in AMSfree:

- The project analysed the architecture of Infrastructure Asset Management Systems (IAMSs) used by National Road Authorities (NRAs), as well as the information content in current IAMSs, to establish detailed technical requirements for linking IAMS and Building Information Models (BIMs) as infrastructure asset databases.
- The use and maturity of BIM in Europe and the existing IFC Model were analysed and described, establishing which content of common IAMS BIM can be handed over from planners and contractors to asset managers.
- An overview of current and new survey and assessment technologies were provided and it was shown how they can be used in the context of BIM-based IAMS. This included new technologies for the assessment of roads and bridges.
- Based on these results an Information Delivery Manual (IDM) for condition assessment was developed as well as the IFC for visualising condition assessment data.
- A generic reference process model was developed and characteristic data updates defined. Data demands for pavements and bridges were defined for this model according to the requirements of national AMS. This included the data drop points and requirements within the IAMS Process.

- Information Containers for Pavements and Bridges were created, as well as the ontologies and the payload documents. This lead to the development of a referenced vendor-free based data structure.
- An IAMS oriented IDM was provided as well as IAMS-oriented application and extension of the IFC Standard.
- A prototype for the data exchange to legacy systems was developed using information containers. A web-based application was tested using a project-related database of different use cases for bridges and pavements.
- The prototype application was described in a guideline for IFC Property Mapping, in a functional memorandum and the description of different use cases.

The outcomes of AMSfree included:

- The process, data handover from as-built models to operational models and the data demand for the operation period were described. The Property sets and properties can be extended related to national demands.
- Relevant data updates regarding the needs of IAMS during the operation period were defined.
- IDM for condition assessment/inspection using new assessment methods were given.
- A linked data concept and prototype for using legacy data bases based on information containers was tested with different use cases. A provided method and workflow makes the approach is scalable.
- The approach will allow asset managers to keep their working routines, legacy databases (incl. valuable data), and software applications. The ICDD contains all relevant data and information referred to one geometric model.
- The approach was tested as a “lab-application”, the next step should demonstrate the approach a real operational environment of a road authority.

AMSfree emphasised that an important component of the overall result is that the AMSfree method does not presume the existence of any specific software, but can be integrated into different software- and data environments. The method can facilitate the handover of data from the construction to the operational phase and data handover between different processes within the operational phase. Therefore, the engineering process in asset management would not need to be changed. The method is ready for use in a real working environment. A test in such an environment should include:

- Extension to the national class model regarding IFC
- Adaption to the national property sets and properties
- Update and adaptation of national process descriptions
- Site tests
- Improvements and implementation plan

PART 2: OUTCOMES OF THE FINAL CONFERENCE

The final conference

A final conference on the CEDR Call 2018 Building Information Modelling (BIM) was held on the 25-26th May 2022 in Stockholm, Sweden. The majority of conference participants attended the event in person. However there was an option for the conference participants to join remotely on the first day. Participants involved mainly CEDR members and project representatives but also members of public authorities and research institutions – see full list of participating organisations in Appendix A.2.1.

Aim and agenda of the final conference

The aim of the conference was to present the results of both projects, discuss the synergies of both projects and the implications for the implementation of the outcomes. Hence the final conference programme included project presentations, highlights, interactive discussion sessions (using live polls), and a demonstration of project results.

- The full programme of the event is provided in Appendix A.1.

Day 1

The first day of the conference started with a welcome from Mr. Gerd Kellermann, chair of the PEB, who thanked everyone for their interest in the topic and attendance of this event. He also highlighted the aim and focus areas of the Call and its importance to the NRAs. The conference then continued with a 90min long presentation on the AMSfree and CoDEC projects and their results. The presentations had a strong emphasis on the project results and recommendations (which have already been summarised in the project descriptions above), and included:

- A General project overview including consortium, objectives, work packages
- Presentation of the main results of each work package in each project
- Presentation of the conclusions and initial recommendations for implementation of the results

The presentations and posters given on AMSfree on Day 1 are provided in Appendix A.3.1, and the presentations given on CoDEC on Day 1 are provided in Appendix A.4.1.

Day 2

The second day focused on the demonstration of the project results, followed by a group discussion on implementation and open questions. The summary of the demonstrations is presented in this section, with the discussion of the projects presented in a later section of this report.

Demonstration of AMSfree project

The presentations given alongside the demonstration of AMSfree on Day 2 are provided in Appendix A.2.2. AMSfree project briefly presented a prototype ICDD – AMSfree platform and the use cases developed in the project:

- Use Case 1 – Inspection. Data exchange using ICDD
- Use Case 2 – Maintenance plan. Data collection using ICDD
- Use Case 3 – Maintenance measures. Connection with existing databases using ICDD

Further information on each Use Case is provided in the posters shown in Appendix A.3.3.

A key outcome of the AMSfree project was the prototype ICDD – AMSfree platform. The key features of the platform were presented as:

- The user interface and functionality
- The project related management of containers
- The manipulation of container content
- The ability to connect with external databases
- The ability to query of container content (using SPARQL query language)

The demonstration of the prototype was given by the AMSfree project team, by practically showing on a screen how the prototype works and explanations the different data exchange steps. The demonstration of the bridge example covered the following:

- Data exchange between the asset manager and bridge inspector. Planned inspection data & classification of bridge component data from the asset management system (integrated "as-built" IFC model) being sent to the inspector via the container (without a database connection) and the condition and damage data from the inspector being provided back to the asset management system using another container.
- Data exchange between the asset manager and the construction team. Planned maintenance data & classification of bridge component data being delivered from the asset management system (components to be maintenance & "as-built" IFC model) to the construction team via the container (without a database connection) and the maintenance information from the construction team returning to the asset management system using another container and an "as-built" IFC model that can be updated.

For the bridge use case the following was highlighted (for the technical approach to data preparation and exchange):

- The information provided as ontology-based data, collected by a contractor
- The changed model provided by a contractor

- The necessary domain ontology provided by the asset manager
- The as-built model provided by the asset manager
- The planned activities provided as semantic data from the IAMS

Demonstration of the pavement example covered the following:

- Data exchange between the asset manager and the pavement inspector. The planned inspection data & and required information, as properties from the asset management system (virtual layer for inspection sections & “as-built” IFC model), going to the pavement inspector via the container (without a database connection) and then the maintenance information from the construction team coming back to the asset management system using another container, with the “as-built” IFC model being updated.
- Data exchange between the asset manager and the construction team. The planned maintenance data & and required information, as properties from asset management system (pavement section to be maintained & “as-built” IFC model), going to the construction team via the container and the modified composition data, as IFC properties from the construction team, returning to the asset management system using another container, with the “as-built” IFC model being updated.

For the pavement use case the following was highlighted (for the technical approach to data preparation and exchange):

- The required data, as a property set template, provided by the asset manager
- The planned activities provided as semantic data from IAMS
- The IFC-Model provided by the asset manager
- The enriched IFC-Model with properties provided by a contractor

Demonstration of CoDEC project

The presentations given alongside the demonstration of CoDEC on Day 2 are provided in Appendix A.4.2. The CoDEC demonstration presented the CoDEC data dictionary, ontology & API and the outcomes of three Pilot Projects. The demonstration of the CoDEC data dictionary explained the dictionary structure for roads, structures, drainage, electrical power and lighting functions and land management. The dictionary content for each static data element included a description and items including the Entity Class; Sub-Class; Types; Element Types; Property Class; Property Name; Property Definition; IFC code; Data Requirement; Format and Constraints

In addition to the static data, a data dictionary for sensors (fixed and mobile) and their data was also presented. The dictionary for each sensor included a description and items including the Object Class; Object Sub-Class; Property Type; Property Name; Property Definition; Data Requirement; Formats and Constraints. The Property sets of the sensor data itself included the Property Name; Property Definition; Data Requirement; Formats; Units and Constraints.

The demonstration of the CoDEC ontology & API demonstration presented an overview of the ontology & API structure and then provided practical examples of how to use the API to filter and extract information about specific assets from the linked database using the API interface.

Although the creation of the ontology and API required extensive IT knowledge and understanding, the end user of API was provided with a simple and intuitive interface.

The demonstration of CoDEC pilot projects included a project videos (these videos are uploaded on https://www.cedr.eu/peb-research-call-2018-bim) that aimed to show how each pilot project met its objectives:

Pilot Project 1. Integration and 3D visualisation of sensor data in a BIM Model of a Tunnel (Implementation Partner: AWV, Belgian-Flemish NRA):

- Enhanced BIM model of a tunnel with CoDEC OTL
- Link BIM model with monitoring data
- Be able to query the data (CoDEC API)
- Advanced 3D visualisation of the entire BIM model

Pilot Project 2. Linking and visualizing condition data with a Bridge BIM model (Implementation Partner: RWS, Dutch NRA):

- Enhanced BIM model of a bridge with CoDEC OTL
- Link BIM model with risk and condition data
- Be able to query the data (CoDEC API)
- 3D visualisation of the entire BIM model, exploring risk and condition data

Pilot Project 3. Enhancing legacy data by linking the BIM model of a Road to a GIS (Implementation Partner: FTIA, Finnish NRA):

- Enhance legacy data in BIM models by linking it to GIS based Asset management systems.
- Showcase linked database for two use cases: enriching existing data (using Lidar inventory survey); add new data (gradient data) into BIM model

Discussion and feedback from the Conference Attendees

The conference included several opportunities for questions and discussion of items that had arisen as a result of the presentations, demonstrations, project activities or recommendations. This included a formal process to obtain the views of attendees via an on-line poll which presented questions to attendees and asked them to respond online.

Discussion of AMSfree

The discussion of AMSfree included a poll on the first day that sought attendee's views on the future of existing databases/systems, and whether it is realistic to develop these into IFC databases. In particular, whether the AMSfree approach for linking legacy databases is scalable to wider application within road authorities. The poll suggested that nearly two thirds of respondents (Figure 24) thought that existing databases will be kept in the future as it is not practical, in the near future, to transition to IFC based databases. However, one third did feel that it would be realistic to establish an IFC database as one source of information.

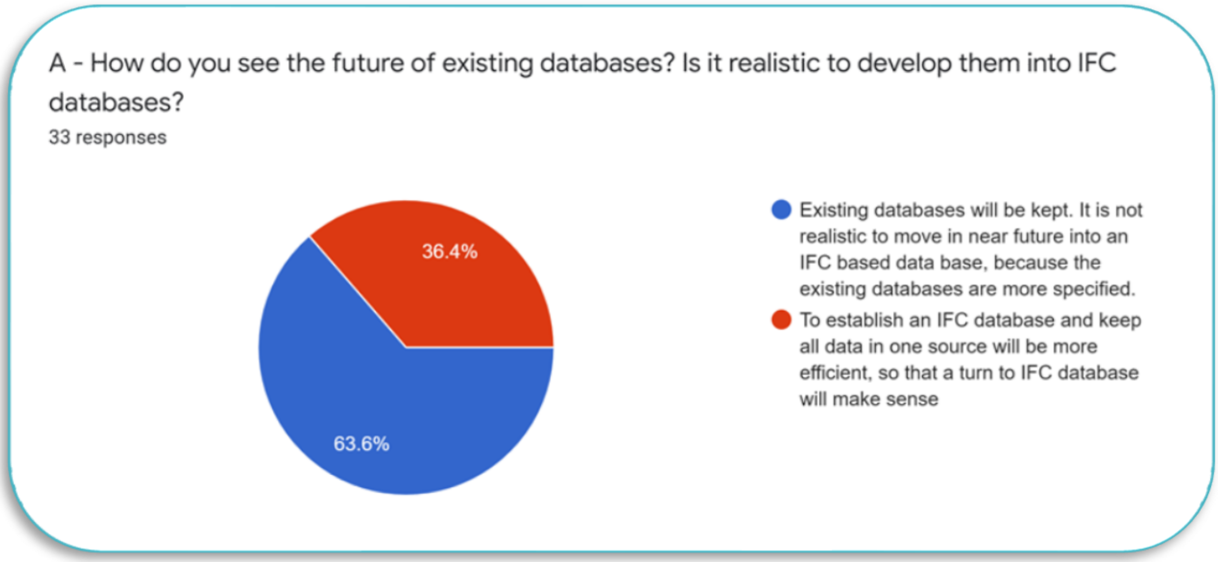


Figure 24: AMSfree poll – views on the future of existing databases

This result led to a discussion, which raised points including:

- Is it really essential to have all this detailed information for asset management? The necessary data needs to be identified, and we can consider extending existing databases with additional data.
- Existing databases contain a significant amount of valuable data (for example bridge databases) and analytical capabilities to project the financial needs, working programmes and make asset decisions. It is very unlikely that legacy databases will change unless that change adds more value.
- The advantage of BIM compared to legacy databases is that geometry data that can be assigned to individual elements, which enables the localisation of damage and the assessment of change over time. Hence geometry data can add value to the existing databases.

When asked about the AMSfree prototype as a method for linking legacy databases, the majority of participants (62%, Figure 25), felt that it could provide an advantage for wider implementation because it enables users to keep their existing tools. However, a significant minority (38%) raised concerns of the amount of IT-knowledge that would be required by engineers. A key take away from the discussion of these results was that IT-knowledge is becoming increasingly important for engineers and will play an even a greater role as an integral part of future engineering.

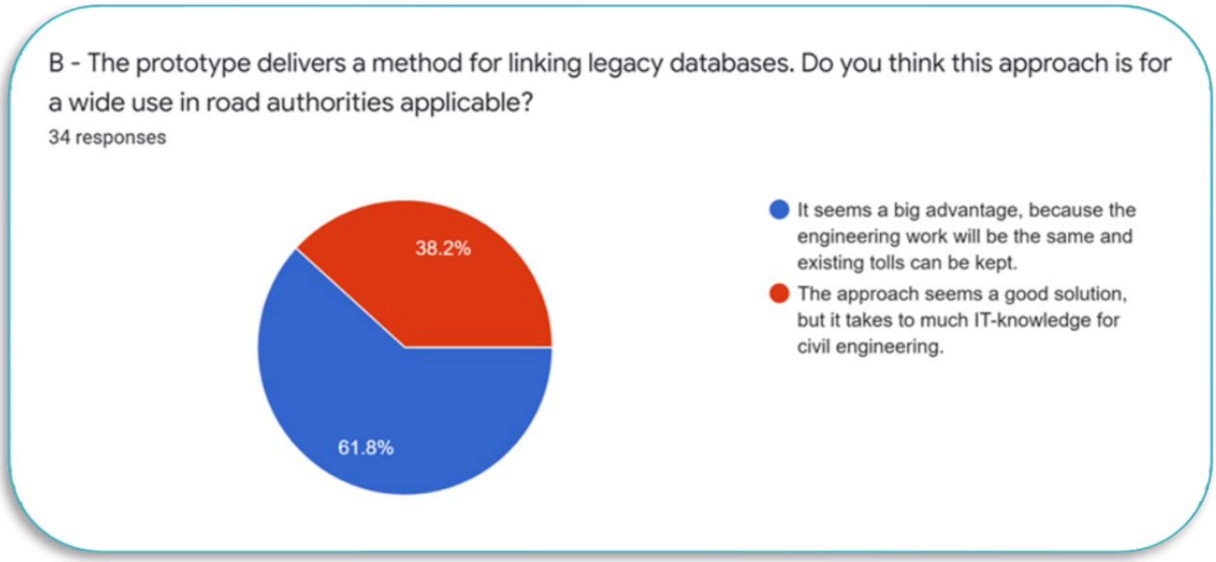


Figure 25: AMSfree poll – views on use of the method by NRAs

Further discussion was held on the AMSfree project, its outcomes and the evidence presented in the demonstration, as summarised in the following:

Discussion of the AMSfree approach led to questions being asked over whether the proposed container approach can be practically connected to link legacy databases. As the Container (ICDD) is a package for delivery and linking to the legacy databases is a different thing.

The AMSfree team stated that the project concentrated on data exchange – the hand- over of linked information. The Prototype is not fully complete, as when the links are stored in containers and imported to a database there is still a need to know where the links are, and the container is needed for the links. Therefore the container needs to be stored so it can be re-loaded to take information from the database and create another container for data exchange.

A follow up question focused on the examples, which showed only IFC files were used. It was asked if maybe the container concept is not needed in such cases?

It was clarified that not only IFC files were used, but the containers also included xml files, images, and additional information (extended properties), as-built models, pdf files etc..

With regard to interoperability between the systems used, what were the main problems/issues encountered throughout the project? Were there any experienced data loss?	*No data loss was experienced. If the export is configured in the correct way then there shouldn't be any information loss. When we are referring to existing legacy systems – pavement management or bridge management, the requirements are connected to the systems. This legacy data is connected to geometry data and when we are connecting geometric elements with semantic elements, then there is no data loss.* *With regard to the general interoperability challenges experienced throughout the project, the issue is that information is stored in different databases (pavement surveys, bridge inspections, general information) and the challenge is how to bring together the data from different systems for asset management purposes. It should also be mentioned that not all legacy data (e.g. raw data) is needed for asset management purposes.*
The project team were asked to comment on the approach of using linked data for data exchange purposes and the effort required for that. It was stated that there may be a lot of effort needed to link everything together. Whilst the idea in principle is good, maybe more simple solutions could be used? For example everything could be linked to a specific geometric point so that the information could be retrieved with a timestamp at that point, which would require much less effort to get the same information about the pavement rather than using an enriched IFC model.	*An IFC model was used in the AMSfree prototype, and information can be linked to a certain station or point. However, there is a need to have something that does the linking. In principle you can just store the coordinates, but it would be better to link to an element that is connected to other elements, which makes it easier to query. For example, if there are 200 elements that need to be linked to the same one document then its irrelevant to do that as you can link the whole project to that document. But in cases where you have data linked to certain elements in the BIM model, it allows easier query for visualisation compared to when the query is made over the coordinates. In the pavement example use of GIS referencing may be sufficient if you only need layer related information. But in more complicated environments, for instance to consider flooding then a 3D model of the pavement and its surroundings would be very useful, and linking with the separate model elements would be of benefit. With regards to the timestamps, there are timestamps included in information containers that can be used, for example for sensor data, and linked with the BIM model.*

Discussion of CoDEC

Day 1

Similarly to AMSfree, a poll was used to seek views of attendees on the use of BIM and its integration with asset management by NRAs. As can be seen in Figure 26, Figure 27 the vast majority of attendees expect BIM to become part of asset management, and more than half already see themselves of users of BIM.

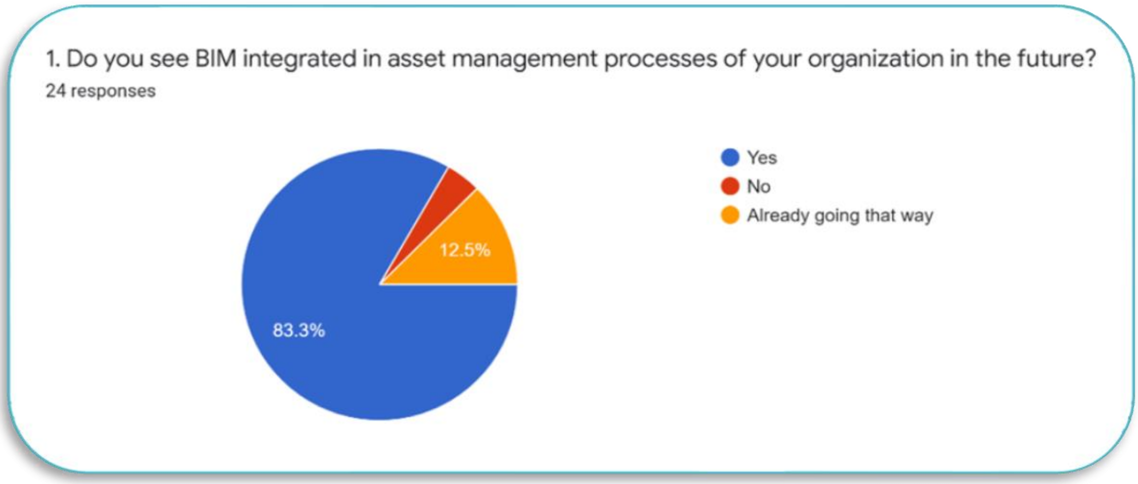


Figure 26: CoDEC poll – expected take up of BIM

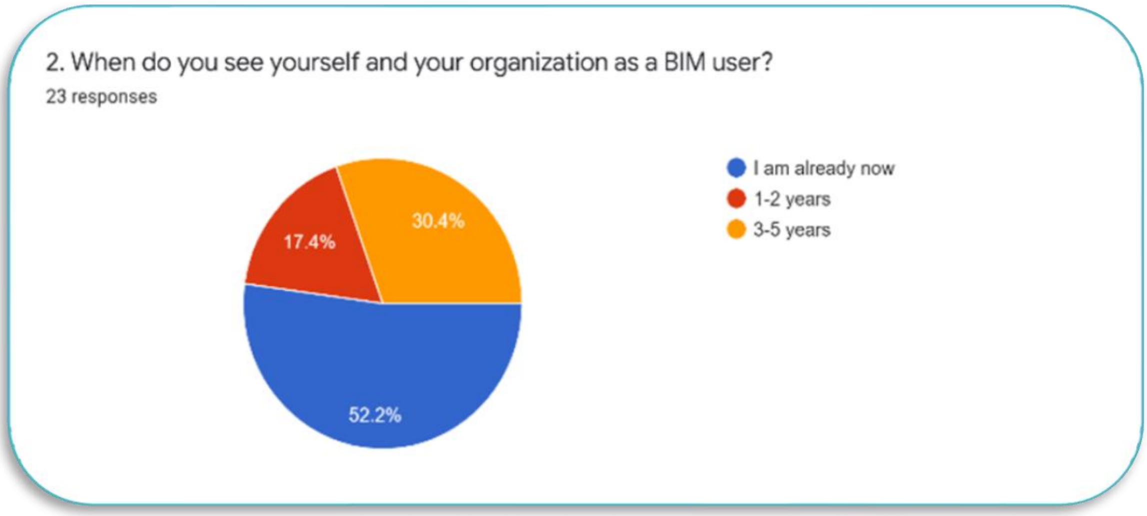


Figure 27: CoDEC poll – expected take up of BIM

When asked their views on the requirements to become BIM users many of the responses were related to skills, knowledge and experience of BIM, having the right systems in place and a culture within the organisation to engage with it (Table 3)

Table 3: CoDEC poll – how do I become a user?

3. What do you need to become an active BIM user (software, knowledge, interoperability with AMS, corporate culture,…)	
More education and practical solutions	A developed BIM strategy
Software	More knowledge about BIM
Corporate culture	Interoperability with AMS
Culture, knowledge	Culture
Classification, standardisation	Programming language, software, knowledge, interoperability
Corporate culture	Little bit from everything
Software, Corporate culture	Interoperability
Knowledge, corporate culture	The key topic is the conceptional information modelling to reach interoperability. It is need for better tools for develop and manage these models.
Knowledge	

With respect to deploying the outcomes of CoDEC a high proportion of respondents felt that the project had some relevance to them (Figure 28). However, a similarly high proportion felt that they would need at least some assistance to achieve this (Figure 29). This reflects the response to the third question above, where skills were a clearly identified need. Indeed, the responses of attendees to the question over what they will do next (Table 4), also suggests some uncertainty over how to move forward with the outcomes within NRAs.

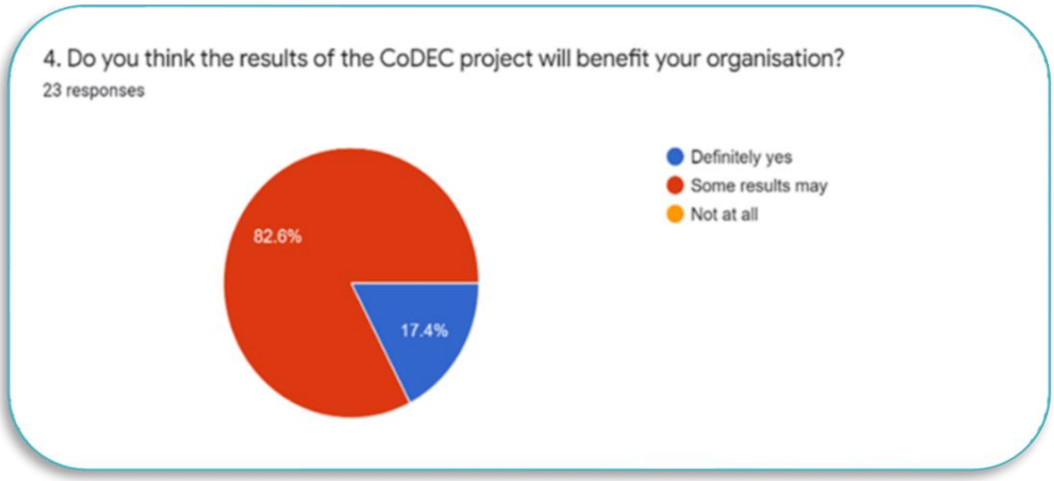


Figure 28: CoDEC poll – Is CoDEC of use to my organisation?

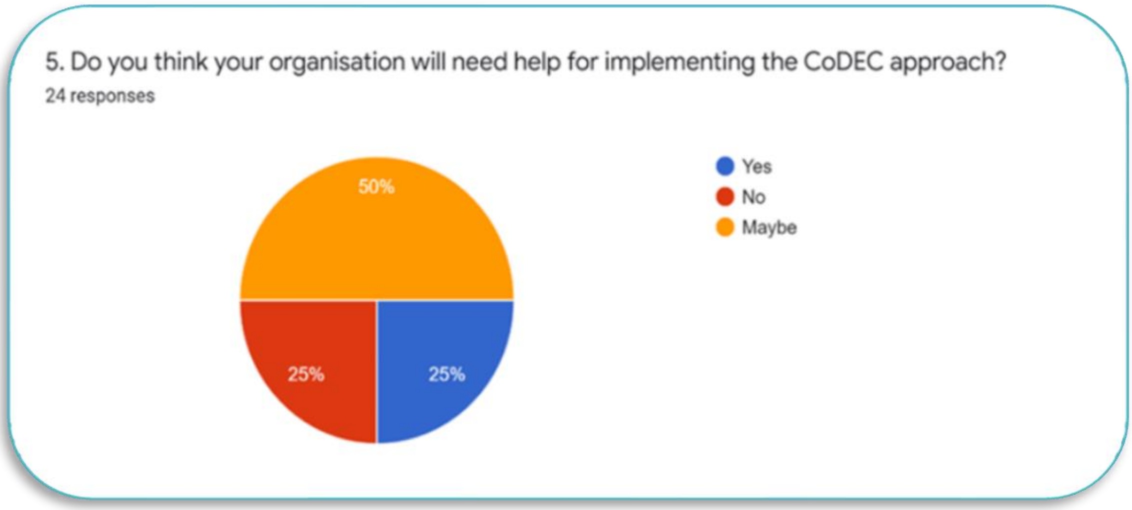


Figure 29: CoDEC poll – How can I implement the results?

Table 4: CoDEC poll – what will you do next?

6. What's next, what will you do with information received today?	
Disseminate Examine more closely Discuss with colleagues Learn from it and disseminate the info Talk to my local NRA for possible implementation.	Digest Use it to illustrate what achieving a BIM organisation. I have to rethink to make up my mind Inform colleagues Useful in our ongoing SW/LD projects

Again as for AMSfree, In addition to the poll there was further opportunity for questions and discussions of items that had arisen during the presentations, summarised in the following.

Could you comment on how CoDEC dealt with IfcOWL and IFC data as RDF?

When we have for example a bridge model and we export it to IfcOWL it is a very huge ontology which is not easy to manipulate. CoDEC feels that it would be useful if BIM tools could provide capabilities to define which things to export to IfcOWL. Although there is an option to export everything to IfcOWL this is not a feasible solution because we would be exporting things that we may not need. Ideally filtering features would be provided in BIM to generate the IfcOWL for the elements we need. To overcome this issue in CoDEC direct transformation to IfcOWL was not used. Instead IfcOWL ontology was used with instances created of that ontology by hand to define information we specifically need.

Do the "BIM models" in the pilot projects refer to just a 3D model without any information attached to the model elements, or to what level of BIM.	*For example, in "pilot project 1" BIM model used was between 200-300 in terms of LOD (level of development), which was sufficient for the purposes of this pilot project. The BIM model contained lots of parameters and some of them were used for implementation for loading and mapping data to model elements.*
What do the project results mean to the organisations from CoDEC consortium?	*For the research/consultancy organisations the outcomes are a very useful step towards the development of digital twins for the road sector. The CoDEC concepts are already being used and further developed in some smaller scale projects on condition monitoring and predictive maintenance. For the software vendors the CoDEC results can be shown to potential clients to showcase what can be developed in this area, to add new functionalities to the software (e.g. some of new functionalities in Bexel Manager were developed during the project that will benefit the existing and future users of that software).*
Is it really beneficial to use linked data if it is too complex?	*It depends on what we are looking at and what to know. For example, if we are just looking at specific elements to see what the risk indicator is then linked data environment is not needed. But if we want to make some reasoning on that, for instance if we have an element which is part of another element and we want to see the risk level of that element and dependency on other elements then linked data simplify the such queries*

Day 2

The discussion of CoDEC included a second Poll undertaken after the demonstration of CoDEC. The responses to the five questions asked are summarised below. It can be seen that attendees did gain new knowledge of this area and saw the potential for linking AMS and BIM, which may not have been clear before (Table 5,

Table 6). However, as reflected by the responses to the questions on the first day, implementation is seen as a significant challenge (

Table 7), and the responses related the specific assets or sensor data to commence implementation were quite vague / generic (

Table 8,Table 9), further reflecting this situation.

Table 5: CoDEC second day – what have we learnt?

1. What new knowledge will you take home?	
Ideas, models to work Call a linked data friend Opportunities and challenges related to visualisation of construction elements Any system might be connected - only a matter of effort Example of visualisation of sensor data in a BIM model Overview to different approaches and ideas	It is technically possible New approaches to Deal with different data Bridge AMS use of BIM 3D Data dictionary for sensors Possibility to integrate BIM with AMS Technically it can be done

Table 6: CoDEC second day – What was useful?

2. What did you find most useful?	
Ideology how to change information BIM GIS connectivity Major principles Hearing the summary of the project Get new impressions on possible solutions	Pilot projects De visualisations Contacts, ideas, discussions Application plus companies how can integrate the data

Table 7: CoDEC second day – How can we implement the outcomes?

3. How can you implement this?	
Needs further thinking Slowly Not at this point, a lot of loose ends Needs more elaboration	Yes, the principles Step by step, talking to IT, AMS, project implementation, and inspection people Via procurement of a it system

Table 8: CoDEC second day – what assets will we start with?

4. For what asset would you implement this first?

Project information to road asset information system.... Probably road basic data first. Bridge Roads	Pavements All of our asset types, ranging from road to bridges to waterways storm surge barriers etc.

Table 9: CoDEC second day – Sensor data in BIM

5. Which sensor or survey data would you primarily like to exploit in combination with BIM?	
Average speed CO_2 Condition data	Bridge sensor IRI, bearing capacity Asphalt related and construction related

Again, after the results of the poll were presented, the audience followed with further technical questions about the CoDEC project outcomes.

There is a challenge that if the BIM model is created with the LOD that is required for construction elements in the building phase that may not be sufficient for the bridge owner to carry out an inspection of the bridge and locate damages. There are differences between the needs of different bridge life cycle stages, for example BIM models for the construction phase are more focused on how to build the bridge while the bridge owner/operator has other needs for the other life cycle stages.

If there is a need to have a BIM model to higher LOD in order to include more features for other life cycle stages, then the requirements should be established for BIM model development to include such higher levels of detail. The example bridge BIM model showed during the demonstration has lower LOD but was sufficient for this particular demonstration.

If the BIM model is going to be used for maintenance then it should have a higher LOD to enable that, or lower LOD when it is not required. There can be a combination of lower and higher LODs in BIM models, for example one LOD for the whole construction with other parts/elements having different LODs depending on the need. That again links back to the recommendation that BIM models should have defined requirements to enable their use over the life cycle and for different purposes.

Although it is an open API that was developed in CoDEC project, can more detail be provided on the inputs required for the API and the outputs provided and whether open source means that it will be available and accessible to anyone.

Open source means that the definitions of the services are public (source code is public) but the interface, although it is public, doesn't mean that everyone can use it without access. Something that was not developed during the project was layer of security of the API which would limit the access to the service to a set of users or particular parts of the service depending on the user.

NRA representatives asked about the possibility to visualise the data in cases where existing assets (e.g. bridges) don't have 3D or BIM models with the required LOD for information management and visualisation. Do the API and systems would work in a similar way without any visualisation?

An example from the Portuguese dam safety management system was provided where there were no BIM models, and all visualisations were done through svg files. While visualisation of the model is in svg, the additional information can be presented on top of that. Hence, the layer of the services can be used by any sort of application – independently. Even if there is no geometric information the visualisation can be done, for example by visualising tables. But if there are BIM models and the tools then the same environment should be used, and visualisation done with that data instead of developing something new.

Discussion of Implementation

Following the technical discussion of the specific project outcomes (above), a further discussion was held on the future for this work area and, in particular, the implementation of the outcomes.

To commence, NRAs were asked to reflect on how well the expectations of the CEDR Call 2018 Building Information Modelling (BIM) programme had been met. It was agreed that, overall, the projects delivered the vision set by CEDR and its NRAs. The results of both projects showed that the aim of the DoRN has been realised. The projects show that we are gradually moving towards a connected data environment, with both projects proving that, with appropriate tools and solutions, it is possible to handle the complex environments that NRAs have. However, it was noted that the implementation is very much about the people. Gaps in knowledge and communication will be the key barriers to implementation. Indeed, the outcomes and deliverables of both projects have been very technical and "IT heavy". An increasing gap in knowledge between IT and civil engineering/asset management sectors was pointed out, which creates difficulties to utilise the full potential of IT/data related technologies and solutions in asset management. Education and/or active cross collaboration between these different sectors is seen to be a way of managing that. In addition to this, close collaboration with infrastructure managers should take place to establish specific cases for implementation that would increase the uptake of new ways of working and the development of tools/solutions. It would be useful to have two-way collaboration to learn from maintenance practitioners, for example to learn from them the best way to capture and report relevant data.

In the light of the discussion of AMSfree, it appears that some vital tools are still missing, and there would be benefit in clarifying what's required to help NRAs procure the right systems. It was pointed out that, although specific tools are missing, the primary need is to define an ontology. This would be followed by the relevant APIs, SPARQL or SQL queries. As these are not easily understood by asset managers deploying visual query language may be of benefit here.

Furthermore, there is a need to further develop and promote ontologies and linked data so that providers/developers of software and tools can agree on the standards and bring these into their own implementations. It was also noted that there is a risk of the data dictionary delivered by CoDEC being "put on the shelf". There would be a need for action to further develop and implement the data dictionary to suit the needs of NRAs.

Nevertheless, despite these challenges, it was pointed out that some progress is being made with regard to implementation. The Belgian (Flemish) NRA is planning to have a system placed on top of their asset management database, which is based on ontology and now being implemented with new data model descriptions for inspection and monitoring data. Building on the ideas of AMSfree, work is also ongoing to implement a simple GUI into the inspection app so that inspectors can fill in the details on maintenance, provide the necessary additional inventory information (that is in property sets defined in ontology) so that the data can be linked back to the database. This would enable monitoring of the performance of the asset's health index and the current state of it.

Summary and recommendations

It can be seen from the above that both the AMSfree and CoDEC projects have made significant progress in demonstrating the potential for linking BIM and traditional Asset Management Systems and the data contained therein. The project outcomes and the discussion of these in the conference have shown that:

- New data (sensors, IoT, live data, crowdsourcing data, Big Data) will be more and more available in the future to support asset management decisions. These new data types will need to be integrated and linked.
- Information exchange between different lifecycles (planning, construction, operation, maintenance) is crucial for asset management. AMSfree and CoDEC have demonstrated practical solutions via pilot projects and live demonstrations that showed the transferability of project results across various NRAs, and the applicability across different assets
- However, there is a strong view from practitioners that legacy databases will still be in use, as they contain valuable information on the historical performance of assets. Although the legacy databases can be different, they will likely need to be connected with other data, and to extract relevant data for AMS
- AMS and BIM both exploit a wide range of data at various levels of detail. Practitioners recognise that not all collected/stored data is needed for asset management and that only relevant data should be used. However, questions remain over the minimum data needed for AMS, which is not yet clearly defined.
- The discussion and polls with attendees at the final conference identified a high level of interest, and is encouraging in relation to further implementation of BIM<->AMS and the project results within NRAs. However, the poll feedback highlighted a question over the ability of NRAs to achieve this, or at least an internal concern over whether they have the ability. This includes the software tools, the technical skills and the strategic vision to achieve the required goals. As some of the required capability and skills are likely to lie outside of NRAs, it is clear that collaboration and communication between stakeholders (road owners, software providers, contractors, inspectors) is going to be important to help achieve the vision and should be encouraged.
- The discussion on the implementation of the results also highlighted concerns over skills and capability. However, it also identified some initial steps to make on the further technical development, including the need to continue work on refining/defining the data dictionary and the ontology so that providers/developers of software and tools can agree on the standards and bring these into their own implementations. Both AMSfree and CoDEC have recommended that a route to continued progress in this direction is to start trialling the project results in real environments, and for NRAs to take proactive steps towards BIM by creating requirements regarding BIM delivery.
- Finally, continued dissemination is essential. The closing conference/workshop provides the opportunity to disseminate the results and for road authorities to "learn" how the results could be implemented. However, to further access/review progress on the implementation of the results follow-up conferences could be organised. Furthermore, to emphasise the need for implementation consideration could be given to a specific CEDR Transnational Road Research Programme Call that seeks to directly implement the results in selected places/countries in Europe.

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Appendix A Final conference material

A.1 Final conference, 24-25 May 2022, Programme

Programme Day 1

13:00	Registration & Business lunch
14:00	**Welcome and introduction**
14:15	**Summary session with internet broadcast: project presentations with Q&A session** • **AMSFree** – Exchange and exploitation of data from Asset Management Systems using vendor free format
15:45	Break
16:00	**CoDEC** – Connected Data for Effective Collaboration
17:30	**UNECE TEM Project Report** - Building Information Modelling (BIM) for road infrastructure: TEM requirements and recommendations
18:00	End of Day 1
19:00	Dinner TBC

Programme Day 2

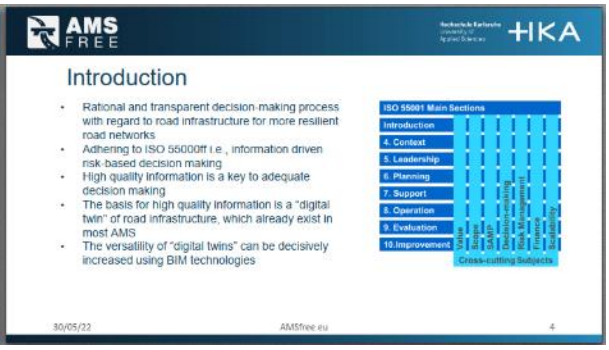
09:00	**Demonstration of projects‘ results followed by group discussion on implementation and open questions:** • **AMSFree**
10:30	Break
10:45	**CoDEC**
12:15	Summary of discussions (implementation issues, open questions, next steps) and closing remarks
12:45	Closing remarks
13:00	End of Conference and lunch

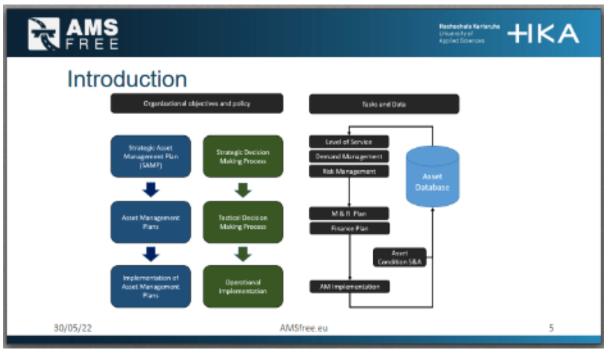
A.2 Participating organisations

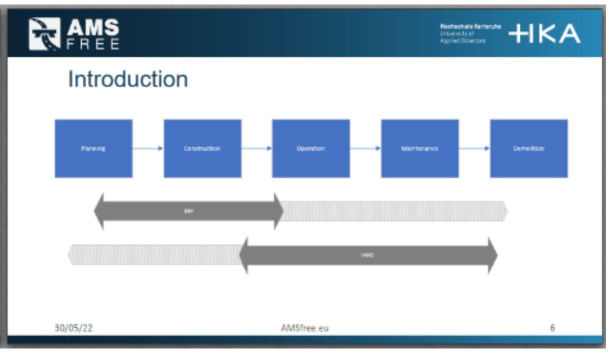
Organisation	Country
CEDR	Belgium
Swedish transport administration - Trafikverket	Sweden
Agentschap wegen en verkeer	Belgium (Flanders)
Danish Road Directorate - Veijdirektoratet	Denmark
Rijkswaterstaat	Netherlands
Väylä	Finland
BASt	Germany
ASFINAG	Austria
Latvian State Roads	Latvia
TII	Ireland
Malta Infrastructure Agency	Malta
Norwegian Public Roads Administration	Norway
GDDKIA	Poland
ECCBIM	Poland
DEGES	Germany
Arup	United Kingdom
TEM	Croatia
TRL *(CoDEC)*	United Kingdom
FEHRL *(CoDEC)*	Belgium
LNEC *(CoDEC)*	Portugal
BEXEL *(CoDEC)*	Slovenia
Royal HaskoningDHV *(CoDEC)*	Netherlands
ZAG (CoDEC)	Slovenia
HKA *(AMSfree)*	Germany
IMC *(AMSfree)*	Switzerland
RUB *(AMSfree)*	Germany
Ingeo *(AMSfree)*	Netherlands

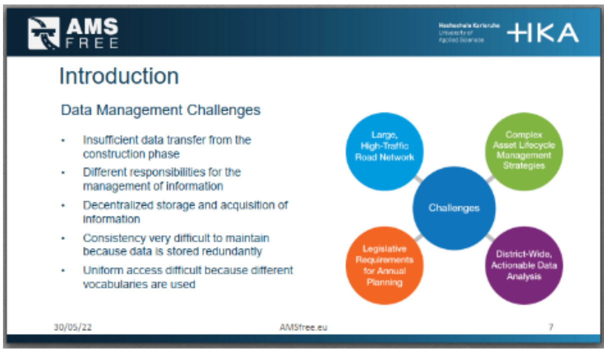
A.3 AMSfree project presentations

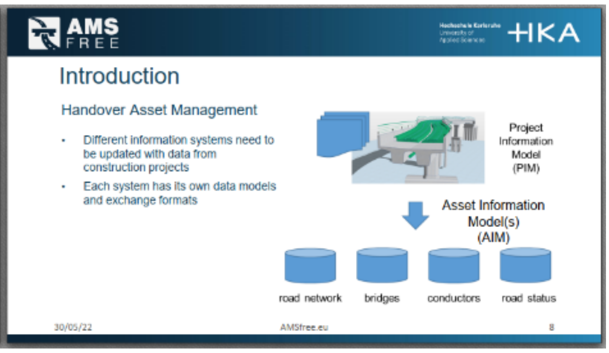
A.3.1 Day 1 presentations

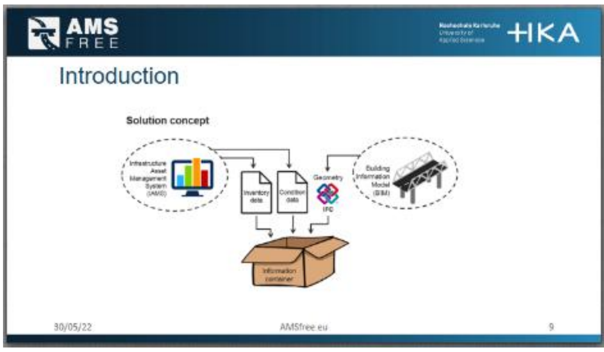











AMS FREE
HKA
Introduction
Solution concept
Infrastructure Asset Management System (IAMS)
Inventory data
Condition data
Geometry
IFC
Building Information Model (BIM)
Information container
30/05/22
AMSfree.eu
9


AMS FREE
HKA
Introduction
Overview Work Packages
WP 1 Project Management
WP 2 Comparative Analysis of IAMS and Common BIM in Europe
WP 3 Digital Condition Assessment
WP 4 Data Fusion and Semantic Transformations
WP 5 Development of a Referenced Vendor-free IFC-based Data Structure
WP 6 Semantic Transformations to Legacy Systems
WP 7 Development of a Prototype
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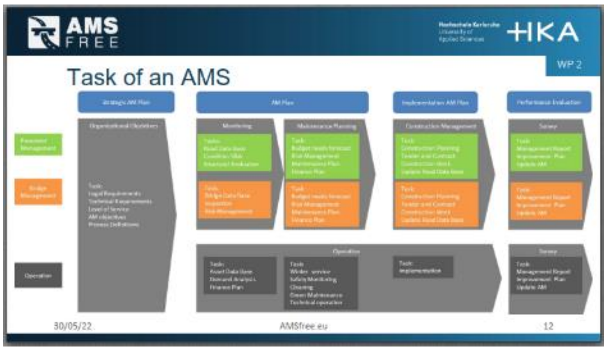
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WP 2
Task of an AMS
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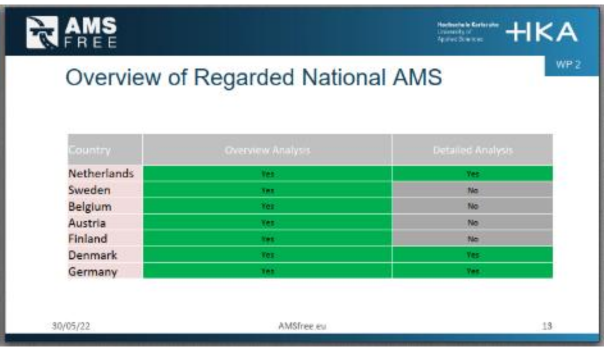
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WP 2
Overview of Regarded National AMS
Country
Overview Analysis
Detailed Analysis
Netherlands
Sweden
Belgium
Austria
Finland
Denmark
Germany
30/05/22
AMSfree.eu
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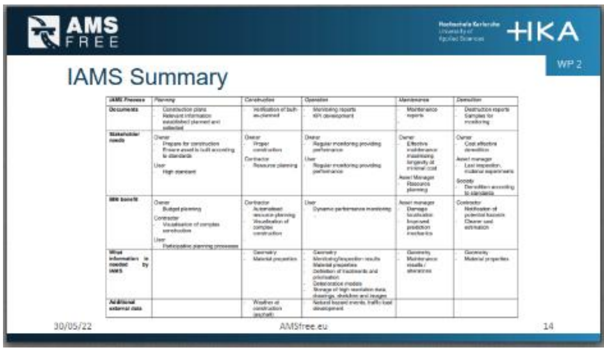
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IAMS Summary
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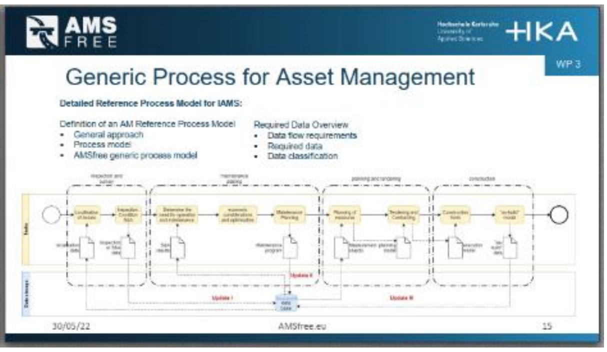
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WP 3
Generic Process for Asset Management
Detailed Reference Process Model for IAMS:
Definition of an AM Reference Process Model
General approach
Process model
AMSfree generic process model
Required Data Overview
Data flow requirements
Required data
Data classification
30/05/22
AMSfree.eu
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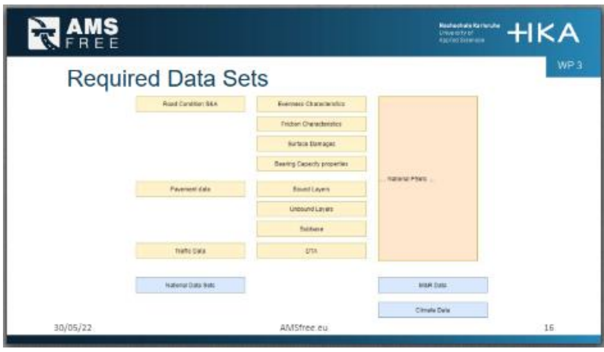
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Required Data Sets
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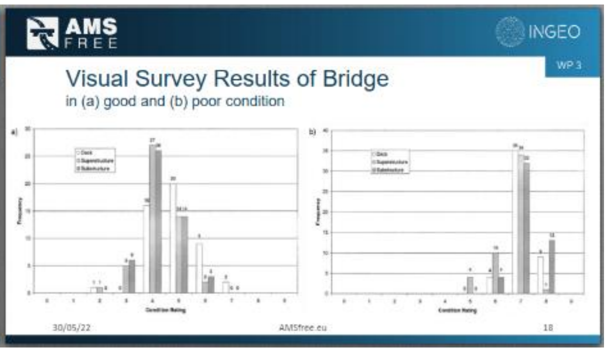
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WP 3
Visual Survey Results of Bridge
in (a) good and (b) poor condition
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AMSfree.eu
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WP 3
Scour driven Collapse in May 2009
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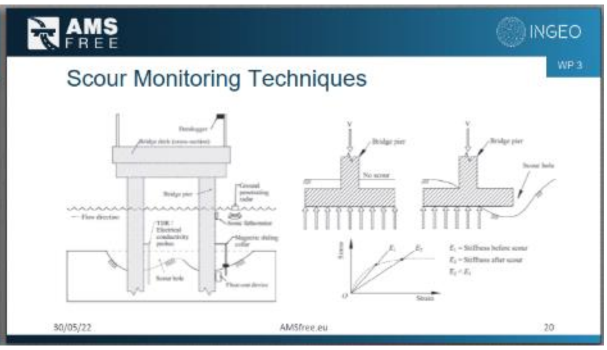
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WP 3
Scour Monitoring Techniques
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Field Trial Baildon Road Bridge UK
Kariyawasam et al. 2019
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AMSfree.eu
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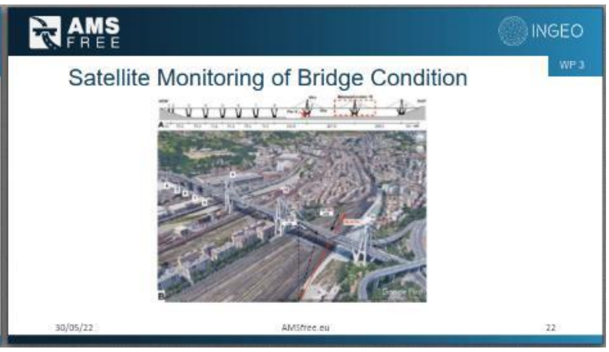
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Satellite Monitoring of Bridge Condition
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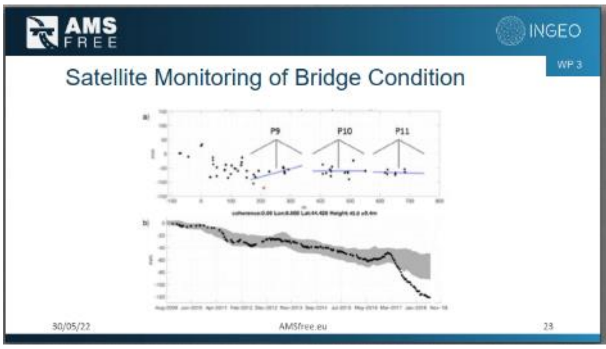
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Satellite Monitoring of Bridge Condition
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P11
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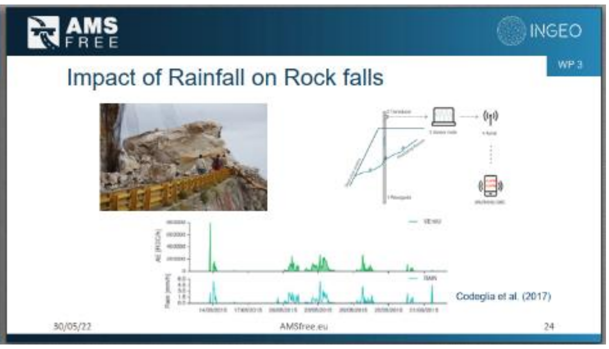
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Impact of Rainfall on Rock falls
Codeglia et al. (2017)
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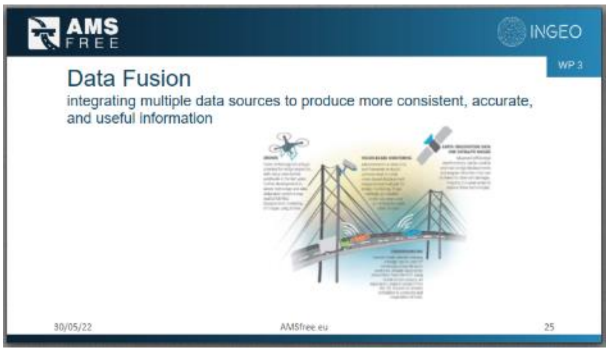
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WP 3
Data Fusion
integrating multiple data sources to produce more consistent, accurate, and useful information
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WP 3
Case Study - Oostmolendijk
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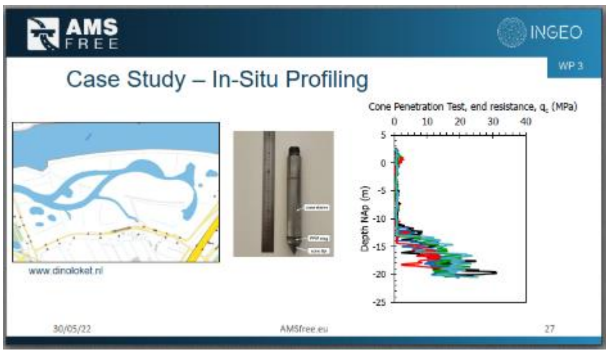
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WP 3
Case Study – In-Situ Profiling
Cone Penetration Test, end resistance, q_c (MPa)
Depth NAp (m)
www.dinoloket.nl
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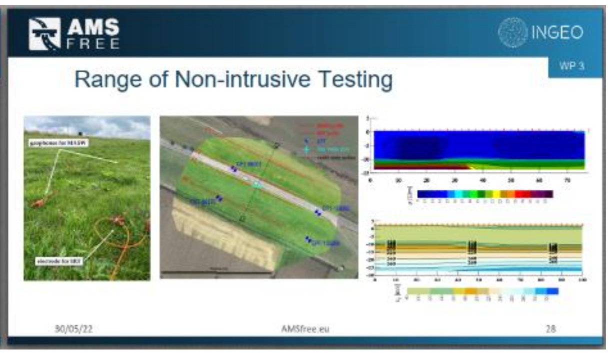
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Range of Non-intrusive Testing
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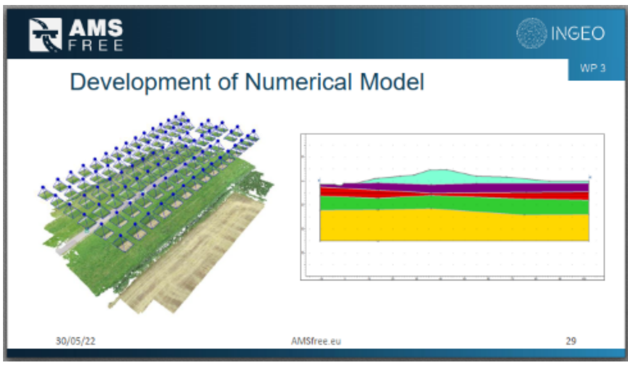
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Development of Numerical Model
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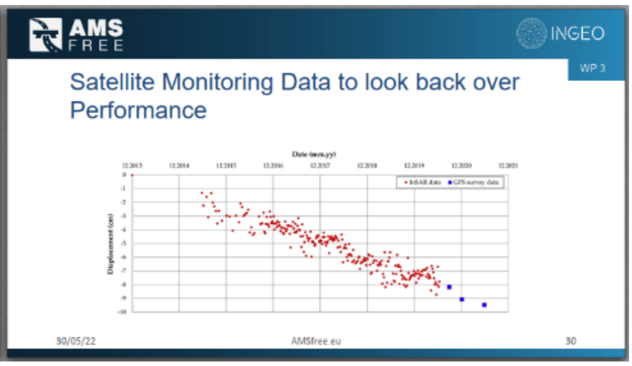
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Satellite Monitoring Data to look back over Performance
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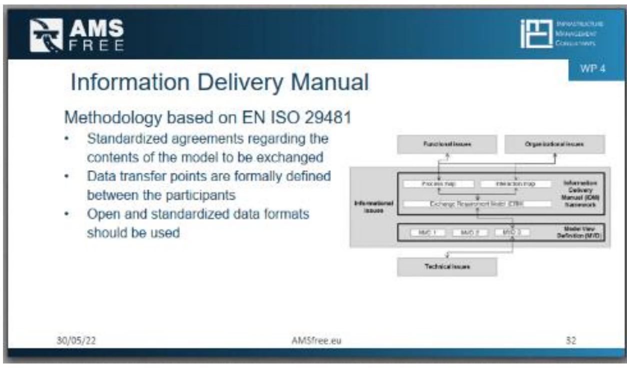
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Information Delivery Manual
Methodology based on EN ISO 29481
Standardized agreements regarding the contents of the model to be exchanged
Data transfer points are formally defined between the participants
Open and standardized data formats should be used
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AMSfree.eu
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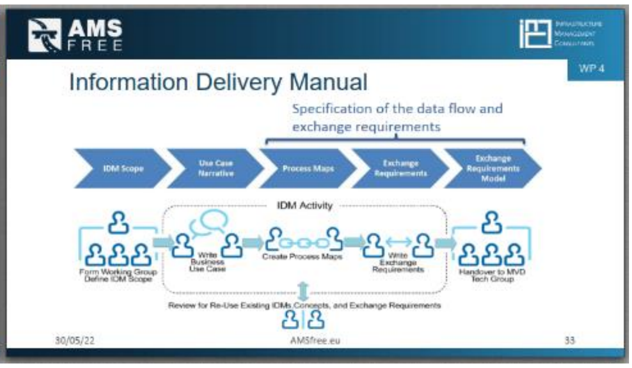
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Information Delivery Manual
Specification of the data flow and exchange requirements
IDM Scope
Use Case Narrative
Process Maps
Exchange Requirements
Exchange Requirements Model
IDM Activity
Form Working Group Define IDM Scope
Write Business Use Case
Create Process Maps
Write Exchange Requirements
Handover to MVD Tech Group
Review for Re-Use Existing IDMs,Concepts, and Exchange Requirements
30/05/22
AMSfree.eu
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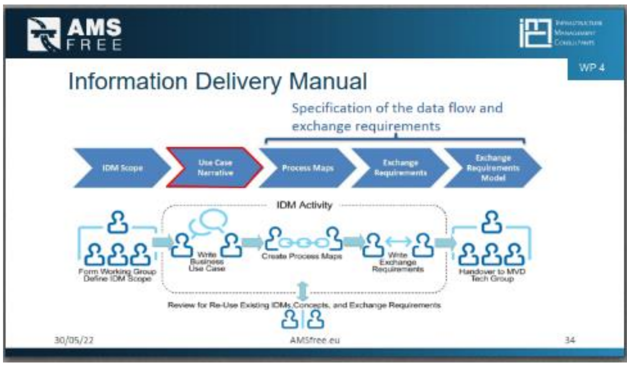
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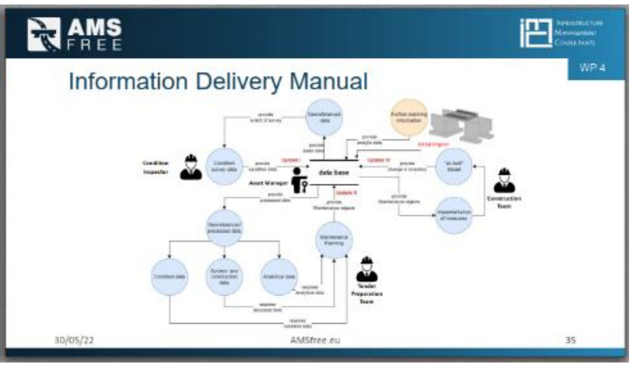
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Information Delivery Manual
data base
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AMSfree.eu
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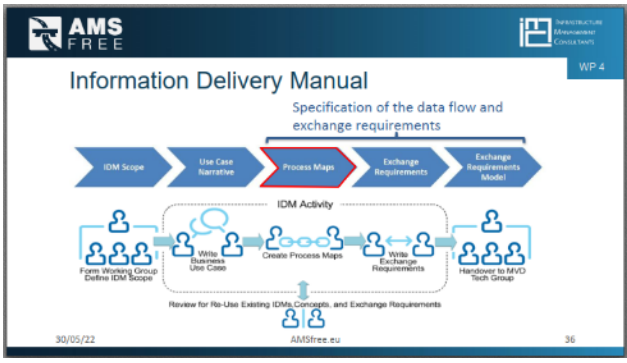
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30/05/22
AMSfree.eu
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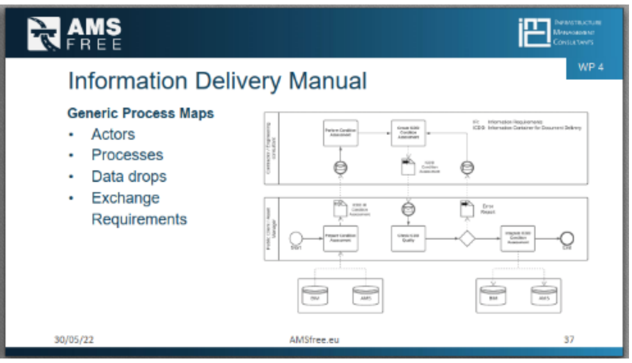
AMS FREE
WP 4
Information Delivery Manual
Generic Process Maps
Actors
Processes
Data drops
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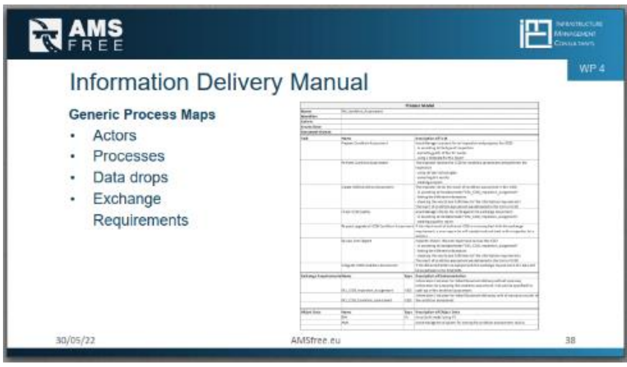
30/05/22
AMSfree.eu
37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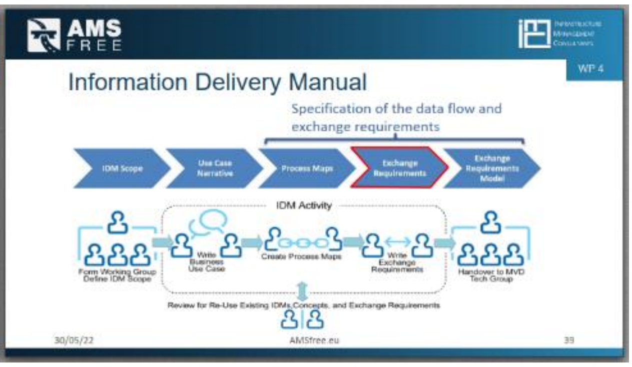
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30/05/22
AMSfree.eu
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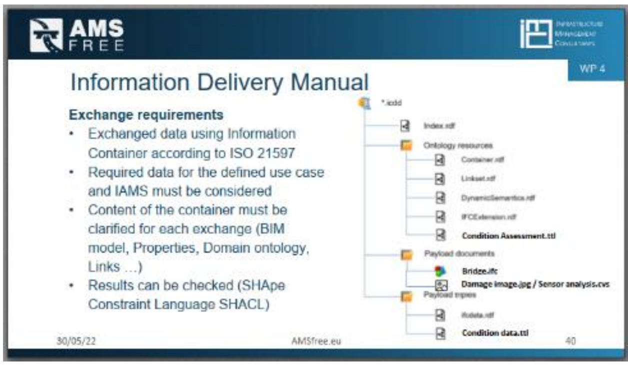
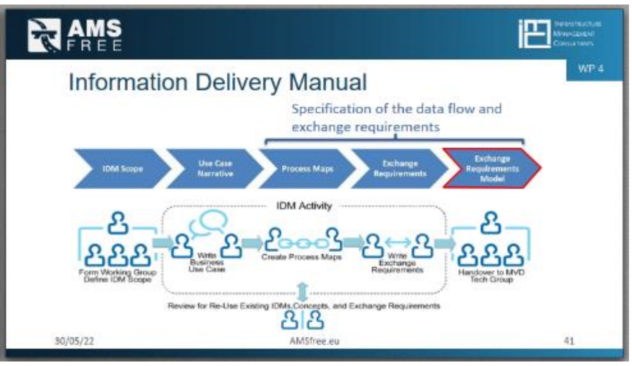

AMS FREE
WP 4
Information Delivery Manual
Exchange requirements
• Exchanged data using Information Container according to ISO 21597
• Required data for the defined use case and IAMS must be considered
• Content of the container must be clarified for each exchange (BIM model, Properties, Domain ontology, Links …)
• Results can be checked (SHApe Constraint Language SHACL)
Index.rdf
Ontology resources
Container.rdf
Linkset.rdf
Condition Assessment.ttl
Payload documents
Bridge.ifc
Damage image.jpg / Sensor analysis.cvs
Payload triples
Condition data.ttl
30/05/22
AMSfree.eu
40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Process Maps
Exchange Requirements
Exchange Requirements Model
IDM Activity
Form Working Group Define IDM Scope
Write Business Use Case
Create Process Maps
Write Exchange Requirements
Handover to MVD Tech Group
Review for Re-Use Existing IDMs,Concepts, and Exchange Requirements
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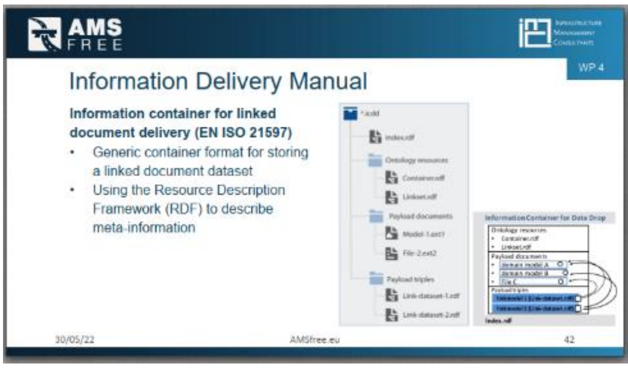
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WP 4
Information Delivery Manual
Information container for linked document delivery (EN ISO 21597)
• Generic container format for storing a linked document dataset
• Using the Resource Description Framework (RDF) to describe meta-information
Index.rdf
Ontology resources
Container.rdf
Linkset.rdf
Payload documents
Payload triples
Information Container for Data Drop
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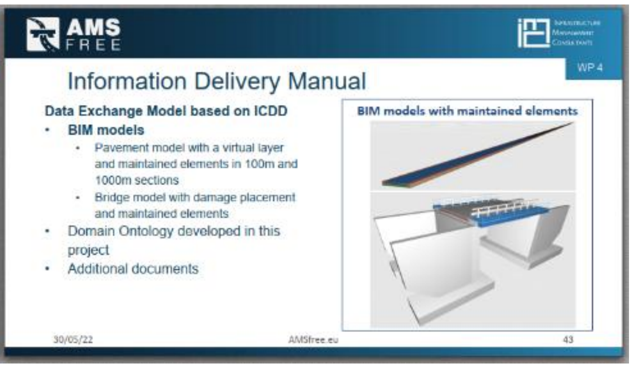
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WP 4
Information Delivery Manual
Data Exchange Model based on ICDD
• BIM models
• Pavement model with a virtual layer and maintained elements in 100m and 1000m sections
• Bridge model with damage placement and maintained elements
• Domain Ontology developed in this project
• Additional documents
BIM models with maintained elements
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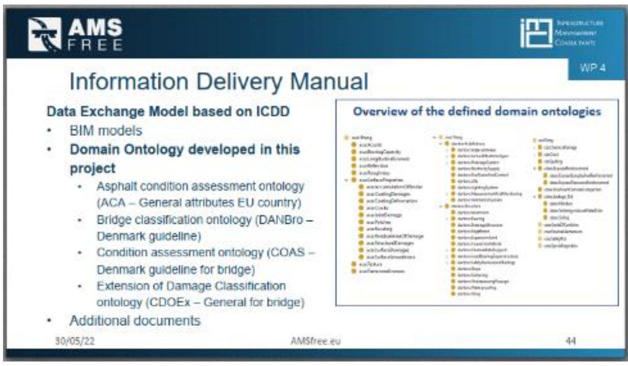
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WP 4
Information Delivery Manual
Data Exchange Model based on ICDD
• BIM models
• Domain Ontology developed in this project
• Asphalt condition assessment ontology (ACA – General attributes EU country)
• Bridge classification ontology (DANBro – Denmark guideline)
• Condition assessment ontology (COAS – Denmark guideline for bridge)
• Extension of Damage Classification ontology (CDOEx – General for bridge)
• Additional documents
Overview of the defined domain ontologies
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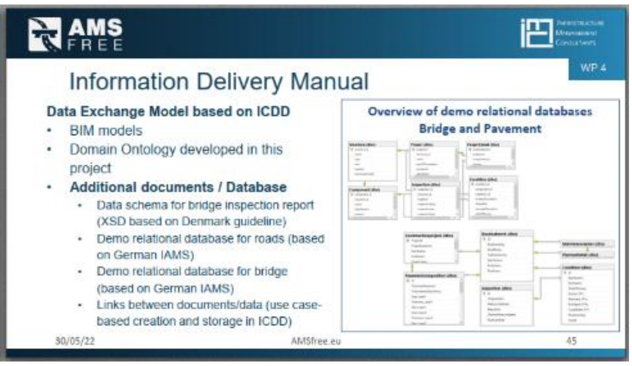
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WP 4
Information Delivery Manual
Data Exchange Model based on ICDD
• BIM models
• Domain Ontology developed in this project
• Additional documents / Database
• Data schema for bridge inspection report (XSD based on Denmark guideline)
• Demo relational database for roads (based on German IAMS)
• Demo relational database for bridge (based on German IAMS)
• Links between documents/data (use case-based creation and storage in ICDD)
Overview of demo relational databases Bridge and Pavement
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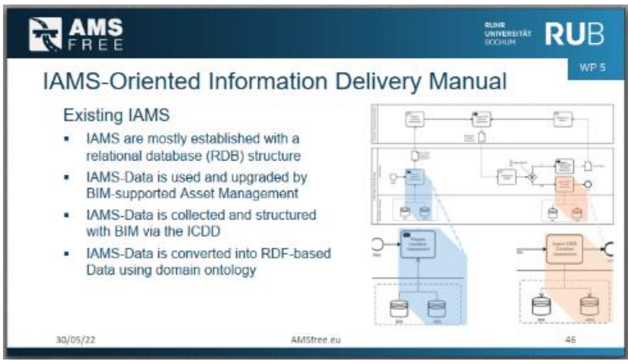
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WP 5
IAMS-Oriented Information Delivery Manual
Existing IAMS
• IAMS are mostly established with a relational database (RDB) structure
• IAMS-Data is used and upgraded by BIM-supported Asset Management
• IAMS-Data is collected and structured with BIM via the ICDD
• IAMS-Data is converted into RDF-based Data using domain ontology
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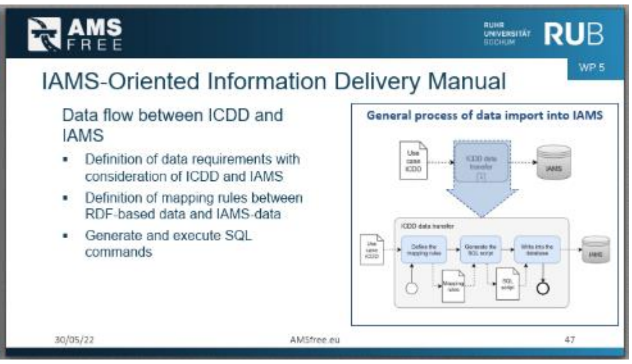
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WP 5
IAMS-Oriented Information Delivery Manual
Data flow between ICDD and IAMS
• Definition of data requirements with consideration of ICDD and IAMS
• Definition of mapping rules between RDF-based data and IAMS-data
• Generate and execute SQL commands
General process of data import into IAMS
ICDD data transfer
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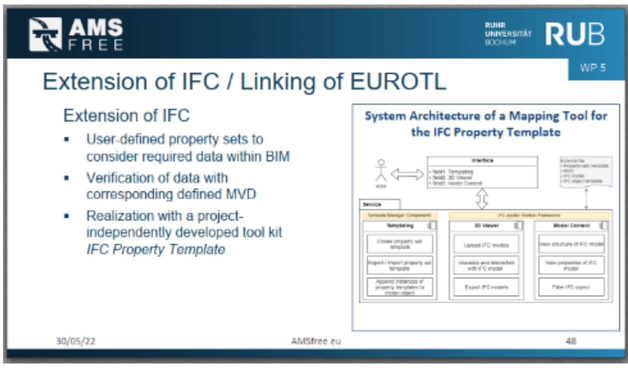
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WP 5
Extension of IFC / Linking of EUROTL
Extension of IFC
User-defined property sets to consider required data within BIM
Verification of data with corresponding defined MVD
Realization with a project-independently developed tool kit IFC Property Template
System Architecture of a Mapping Tool for the IFC Property Template
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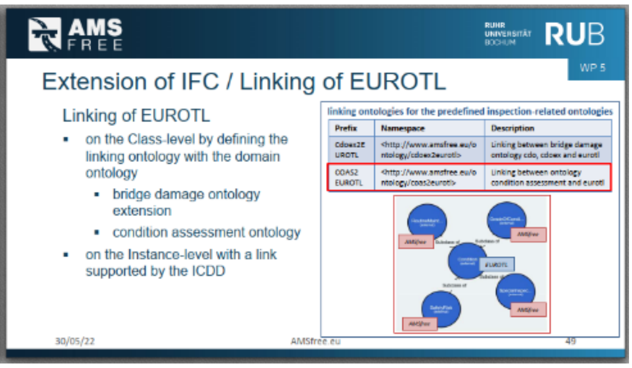
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WP 5
Extension of IFC / Linking of EUROTL
Linking of EUROTL
on the Class-level by defining the linking ontology with the domain ontology
bridge damage ontology extension
condition assessment ontology
on the Instance-level with a link supported by the ICDD
linking ontologies for the predefined inspection-related ontologies
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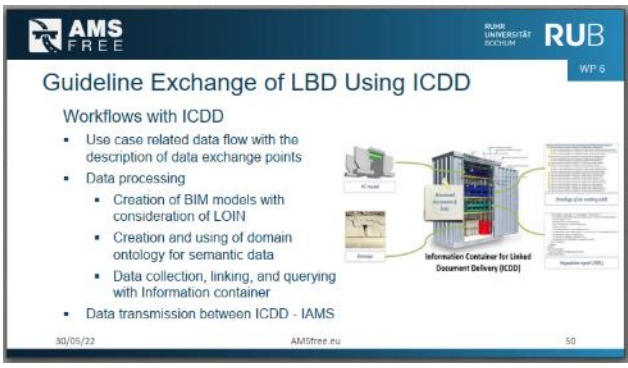
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WP 6
Guideline Exchange of LBD Using ICDD
Workflows with ICDD
Use case related data flow with the description of data exchange points
Data processing
Creation of BIM models with consideration of LOIN
Creation and using of domain ontology for semantic data
Data collection, linking, and querying with Information container
Data transmission between ICDD - IAMS
Information Container for Linked Document Delivery (ICDD)
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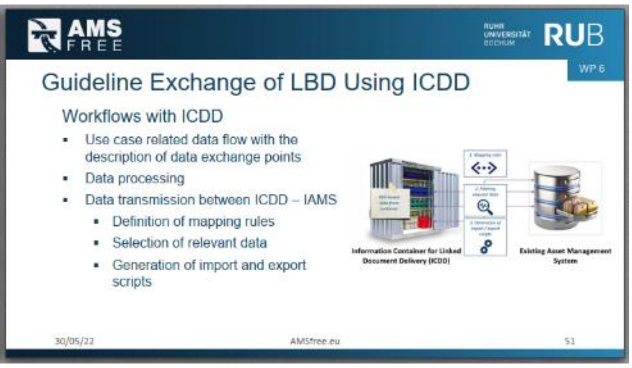
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WP 6
Guideline Exchange of LBD Using ICDD
Workflows with ICDD
Use case related data flow with the description of data exchange points
Data processing
Data transmission between ICDD – IAMS
Definition of mapping rules
Selection of relevant data
Generation of import and export scripts
Information Container for Linked Document Delivery (ICDD)
Existing Asset Management System
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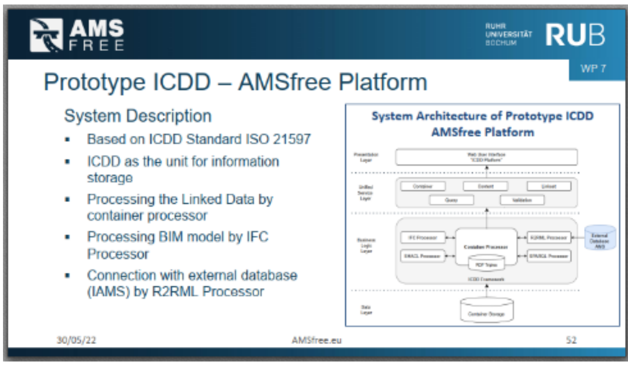
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WP 7
Prototype ICDD – AMSfree Platform
System Description
Based on ICDD Standard ISO 21597
ICDD as the unit for information storage
Processing the Linked Data by container processor
Processing BIM model by IFC Processor
Connection with external database (IAMS) by R2RML Processor
System Architecture of Prototype ICDD AMSfree Platform
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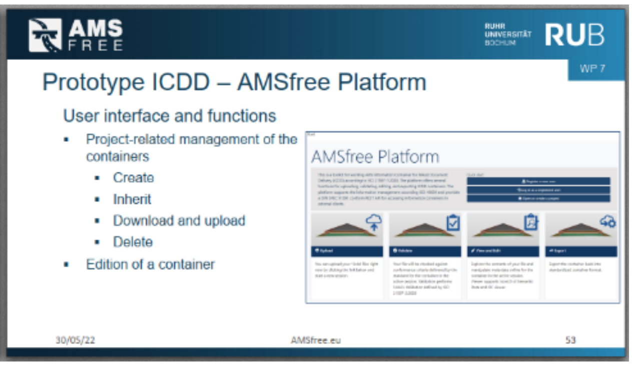
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WP 7
Prototype ICDD – AMSfree Platform
User interface and functions
Project-related management of the containers
Create
Inherit
Download and upload
Delete
Edition of a container
AMSfree Platform
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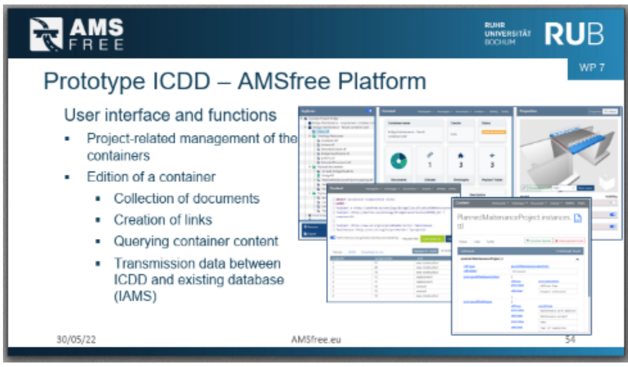
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WP 7
Prototype ICDD – AMSfree Platform
User interface and functions
Project-related management of the containers
Edition of a container
Collection of documents
Creation of links
Querying container content
Transmission data between ICDD and existing database (IAMS)
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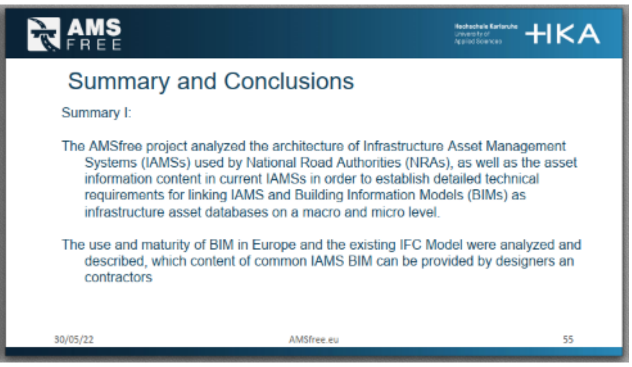
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Summary and Conclusions
Summary I:
The AMSfree project analyzed the architecture of Infrastructure Asset Management Systems (IAMSs) used by National Road Authorities (NRAs), as well as the asset information content in current IAMSs in order to establish detailed technical requirements for linking IAMS and Building Information Models (BIMs) as infrastructure asset databases on a macro and micro level.
The use and maturity of BIM in Europe and the existing IFC Model were analyzed and described, which content of common IAMS BIM can be provided by designers an contractors
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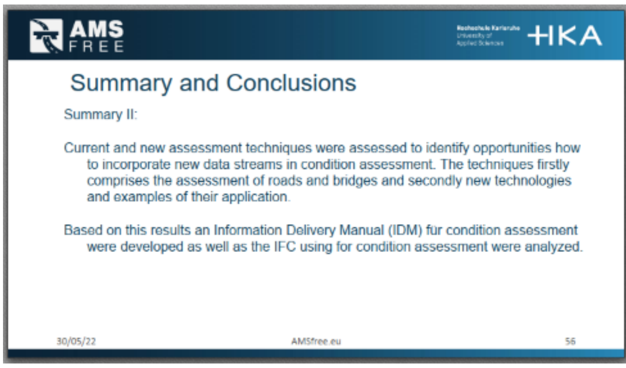
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Summary and Conclusions
Summary II:
Current and new assessment techniques were assessed to identify opportunities how to incorporate new data streams in condition assessment. The techniques firstly comprises the assessment of roads and bridges and secondly new technologies and examples of their application.
Based on this results an Information Delivery Manual (IDM) fur condition assessment were developed as well as the IFC using for condition assessment were analyzed.
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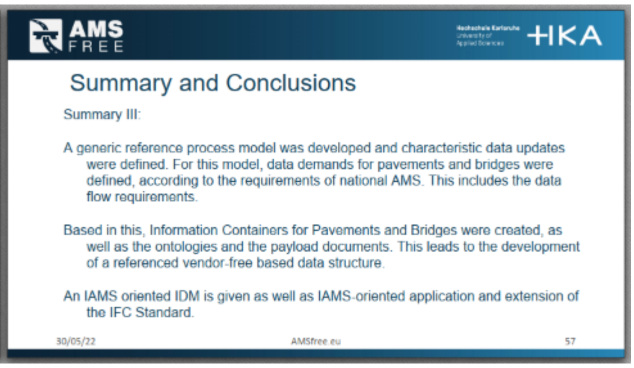
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Summary and Conclusions
Summary III:
A generic reference process model was developed and characteristic data updates were defined. For this model, data demands for pavements and bridges were defined, according to the requirements of national AMS. This includes the data flow requirements.
Based in this, Information Containers for Pavements and Bridges were created, as well as the ontologies and the payload documents. This leads to the development of a referenced vendor-free based data structure.
An IAMS oriented IDM is given as well as IAMS-oriented application and extension of the IFC Standard.
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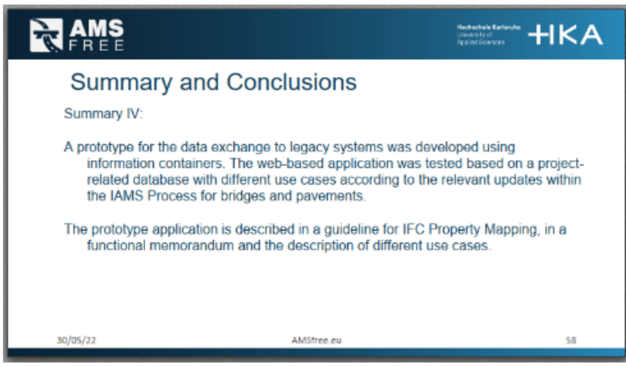
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Summary and Conclusions
Summary IV:
A prototype for the data exchange to legacy systems was developed using information containers. The web-based application was tested based on a project-related database with different use cases according to the relevant updates within the IAMS Process for bridges and pavements.
The prototype application is described in a guideline for IFC Property Mapping, in a functional memorandum and the description of different use cases.
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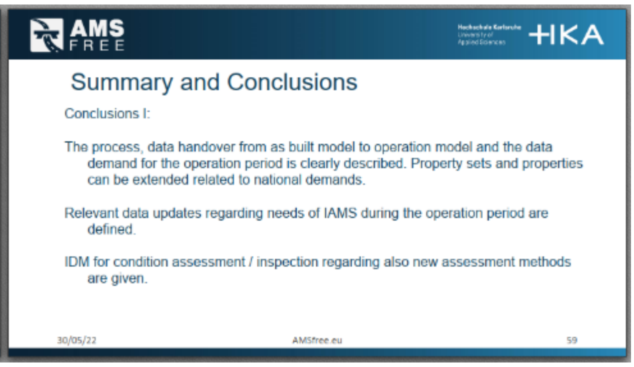
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Summary and Conclusions
Conclusions I:
The process, data handover from as built model to operation model and the data demand for the operation period is clearly described. Property sets and properties can be extended related to national demands.
Relevant data updates regarding needs of IAMS during the operation period are defined.
IDM for condition assessment / inspection regarding also new assessment methods are given.
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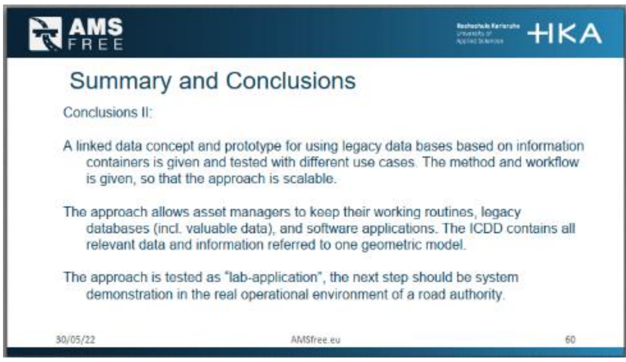
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Summary and Conclusions
Conclusions II:
A linked data concept and prototype for using legacy data bases based on information containers is given and tested with different use cases. The method and workflow is given, so that the approach is scalable.
The approach allows asset managers to keep their working routines, legacy databases (incl. valuable data), and software applications. The ICDD contains all relevant data and information referred to one geometric model.
The approach is tested as "lab-application", the next step should be system demonstration in the real operational environment of a road authority.
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Interactive
Session
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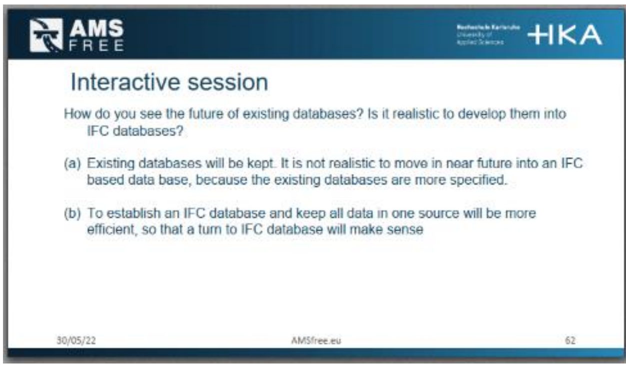
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Interactive session
How do you see the future of existing databases? Is it realistic to develop them into IFC databases?
(a) Existing databases will be kept. It is not realistic to move in near future into an IFC based data base, because the existing databases are more specified.
(b) To establish an IFC database and keep all data in one source will be more efficient, so that a turn to IFC database will make sense
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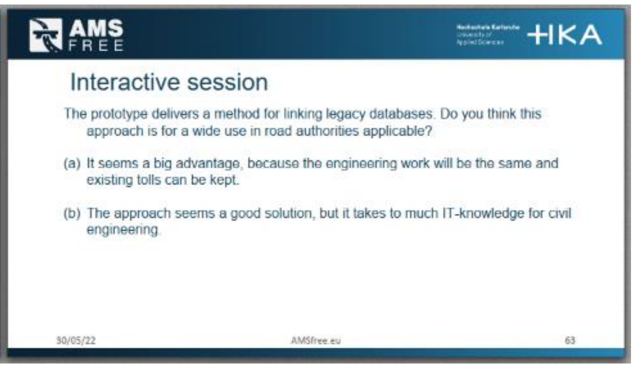
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Interactive session
The prototype delivers a method for linking legacy databases. Do you think this approach is for a wide use in road authorities applicable?
(a) It seems a big advantage, because the engineering work will be the same and existing tolls can be kept.
(b) The approach seems a good solution, but it takes to much IT-knowledge for civil engineering.
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Interactive Session – Live Poll
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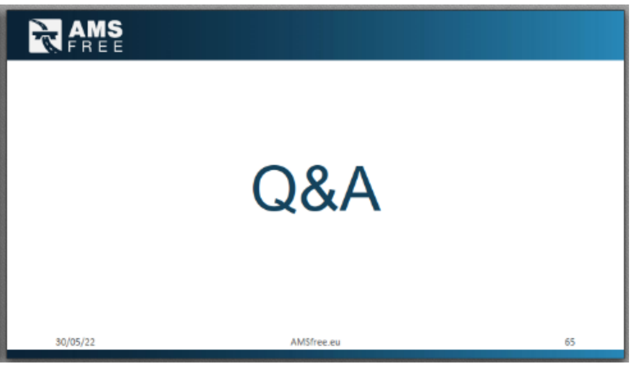
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Q&A
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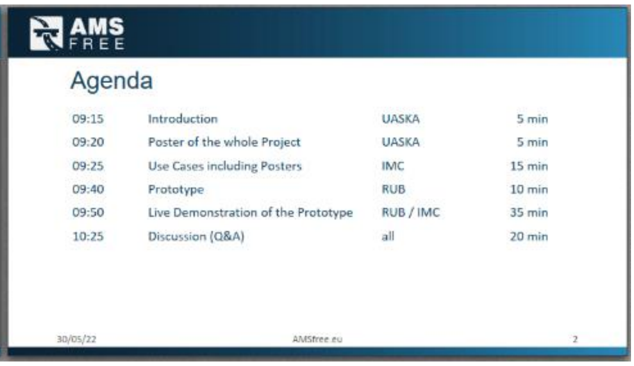
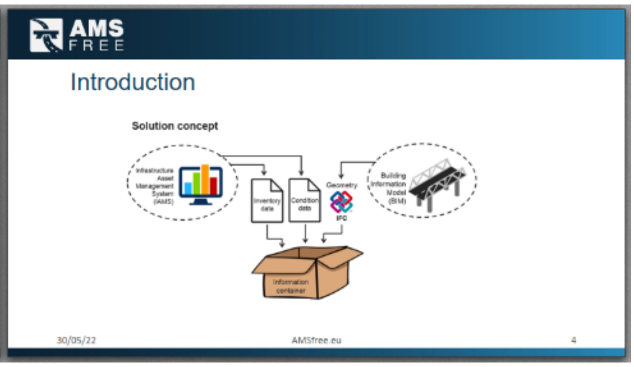
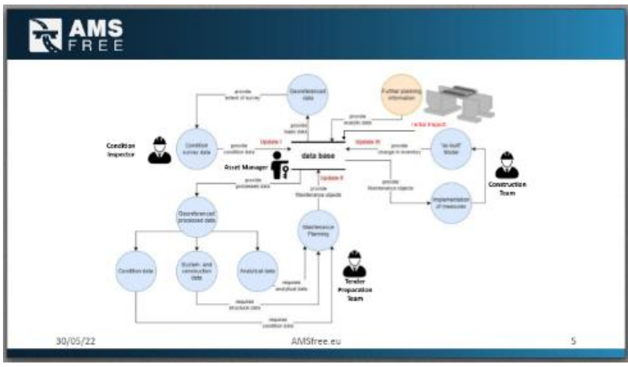
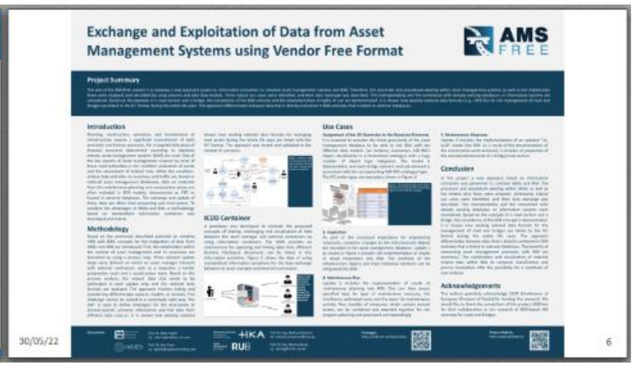
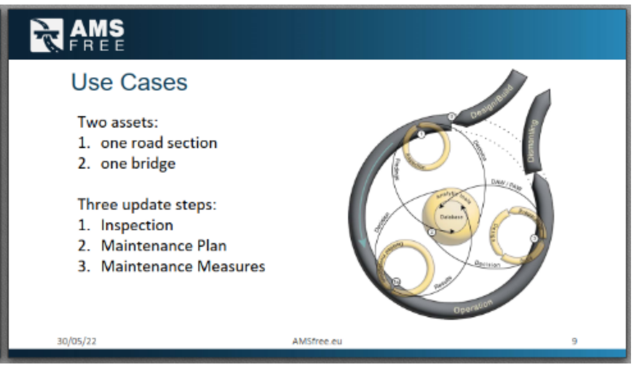
A.3.2 Day 2 presentations

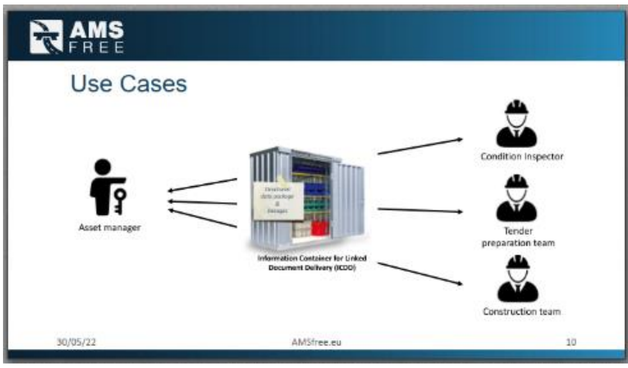








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Use Cases
Asset manager
Information Container for Linked Document Delivery (ICDD)
Condition inspector
Tender preparation team
Construction team
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Use Cases
ICDD Platform
ICDD Platform
ICDD Platform
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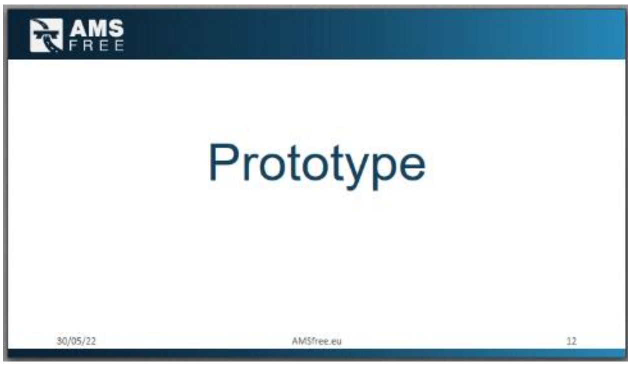
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Prototype
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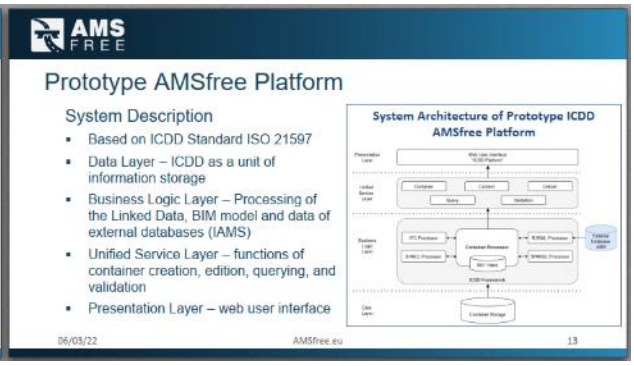
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Prototype AMSfree Platform
System Description
Based on ICDD Standard ISO 21597
Data Layer – ICDD as a unit of information storage
Business Logic Layer – Processing of the Linked Data, BIM model and data of external databases (IAMS)
Unified Service Layer – functions of container creation, edition, querying, and validation
Presentation Layer – web user interface
System Architecture of Prototype ICDD AMSfree Platform
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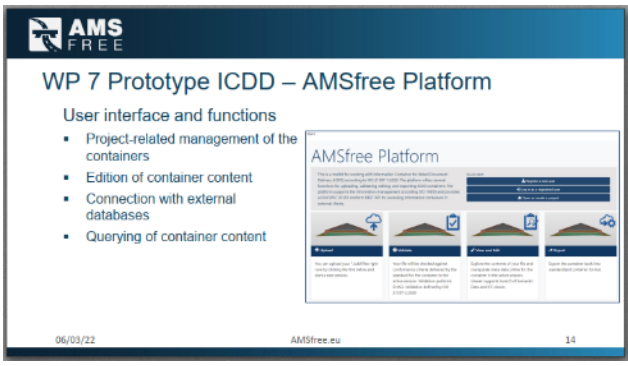
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WP 7 Prototype ICDD – AMSfree Platform
User interface and functions
Project-related management of the containers
Edition of container content
Connection with external databases
Querying of container content
AMSfree Platform
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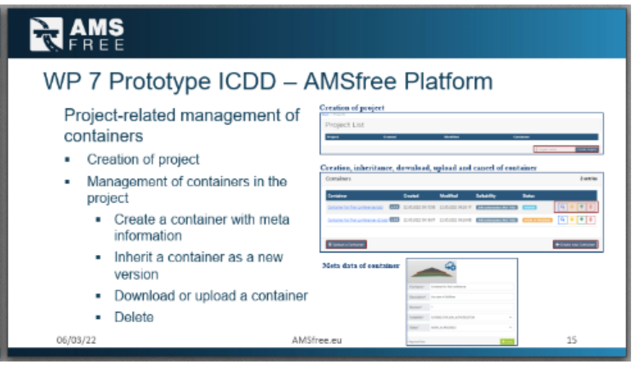
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WP 7 Prototype ICDD – AMSfree Platform
Project-related management of containers
Creation of project
Management of containers in the project
Create a container with meta information
Inherit a container as a new version
Download or upload a container
Delete
Creation of project
Creation, inheritance, download, upload and cancel of containers
Meta data of container
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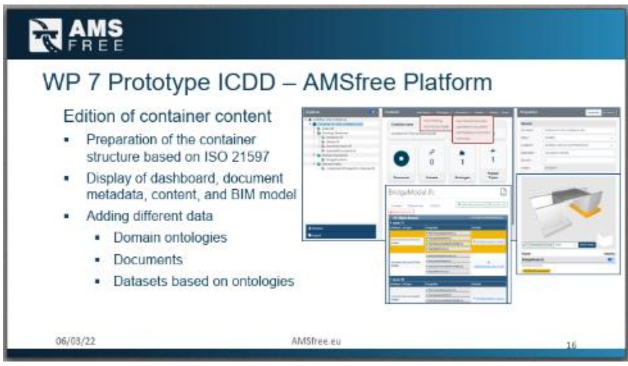
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WP 7 Prototype ICDD – AMSfree Platform
Edition of container content
Preparation of the container structure based on ISO 21597
Display of dashboard, document metadata, content, and BIM model
Adding different data
Domain ontologies
Documents
Datasets based on ontologies
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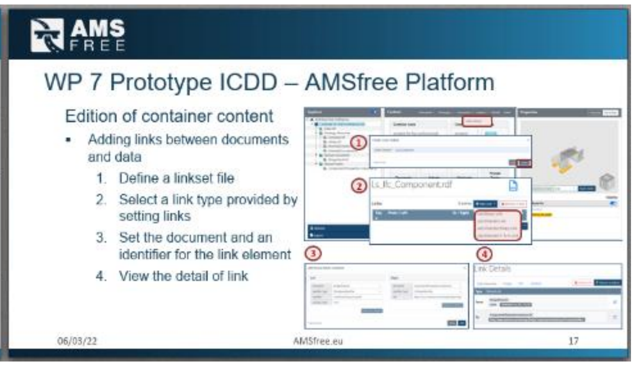
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WP 7 Prototype ICDD – AMSfree Platform
Edition of container content
Adding links between documents and data
1. Define a linkset file
2. Select a link type provided by setting links
3. Set the document and an identifier for the link element
4. View the detail of link
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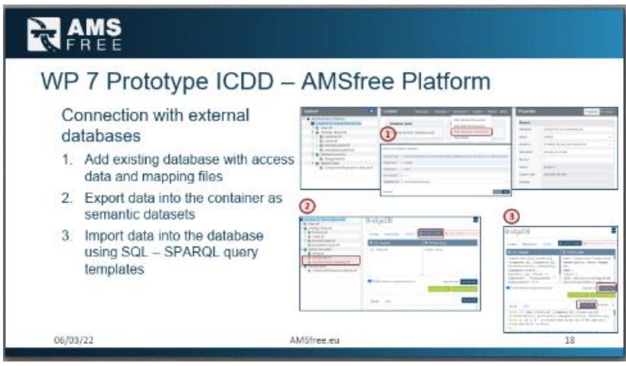
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WP 7 Prototype ICDD – AMSfree Platform
Connection with external databases
1. Add existing database with access data and mapping files
2. Export data into the container as semantic datasets
3. Import data into the database using SQL – SPARQL query templates
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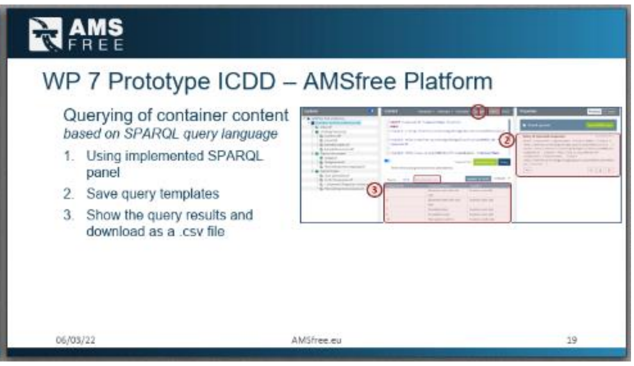
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WP 7 Prototype ICDD – AMSfree Platform
Querying of container content based on SPARQL query language
1. Using implemented SPARQL panel
2. Save query templates
3. Show the query results and download as a .csv file
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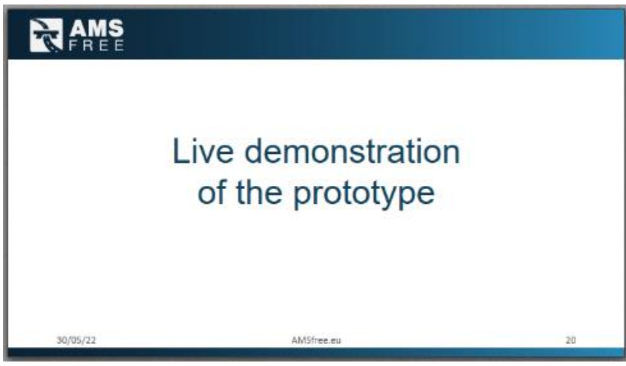
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Live demonstration of the prototype
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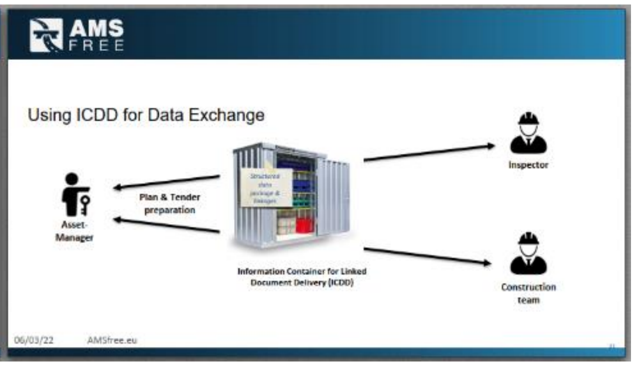
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Using ICDD for Data Exchange
Inspector
Plan & Tender preparation
Asset-Manager
Information Container for Linked Document Delivery (ICDD)
Construction team
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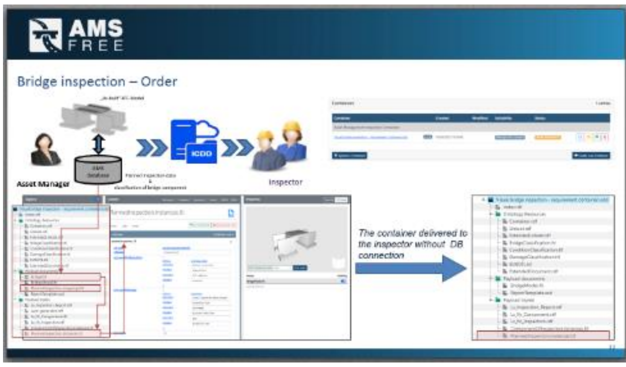
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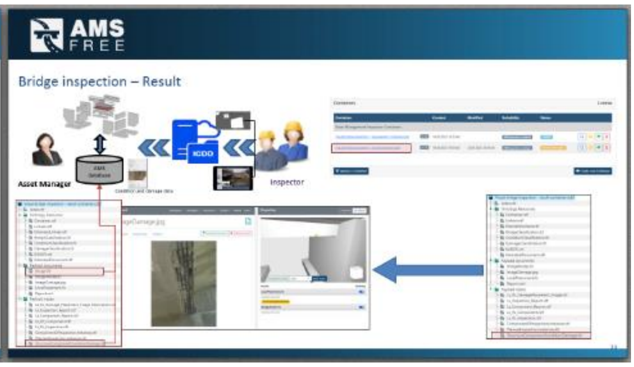
Bridge inspection – Order
Asset Manager
Inspector
ICDD
The container delivered to the inspector without DB connection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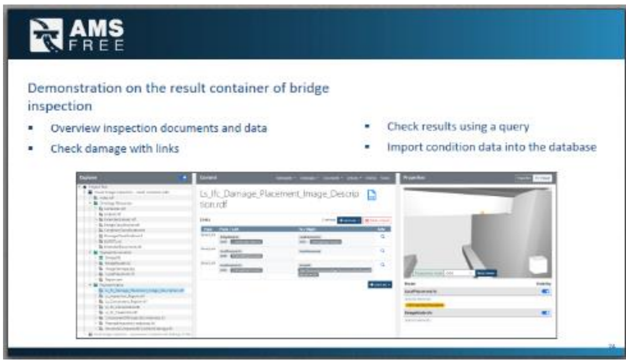
Bridge inspection – Result
Asset Manager
Inspector
ICDD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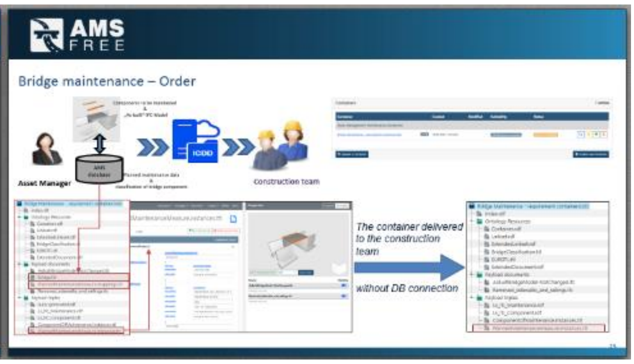
Demonstration on the result container of bridge inspection
Overview inspection documents and data
Check damage with links
Check results using a query
Import condition data into the database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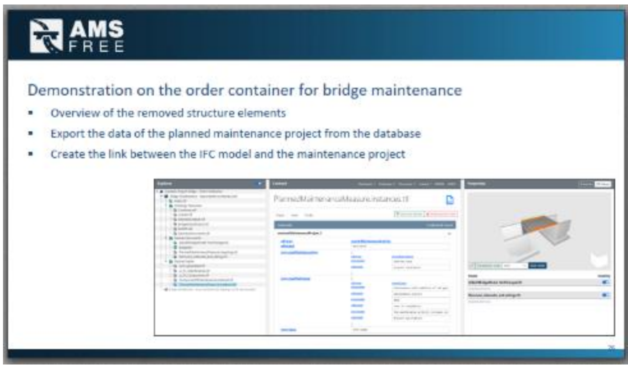
Bridge maintenance – Order
Asset Manager
Construction team
ICDD
The container delivered to the construction team
without DB connection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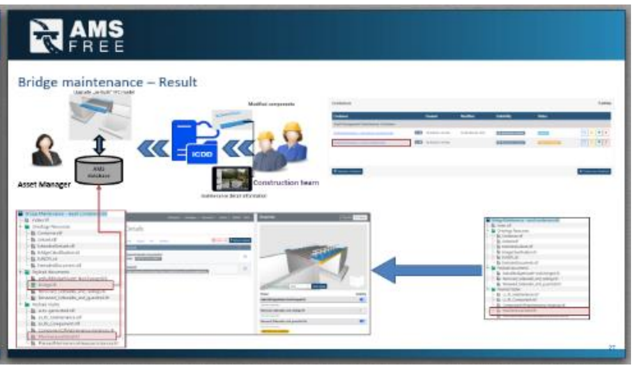
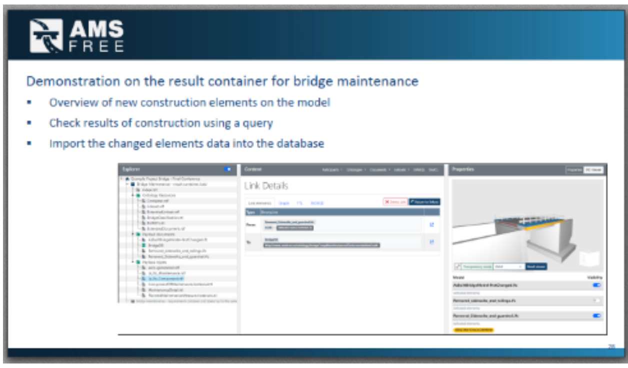
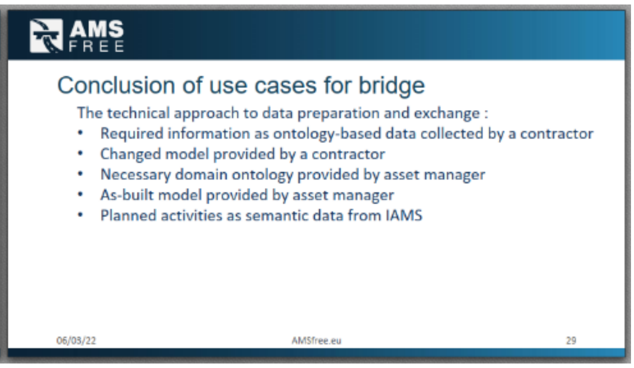
Demonstration on the order container for bridge maintenance
Overview of the removed structure elements
Export the data of the planned maintenance project from the database
Create the link between the IFC model and the maintenance project

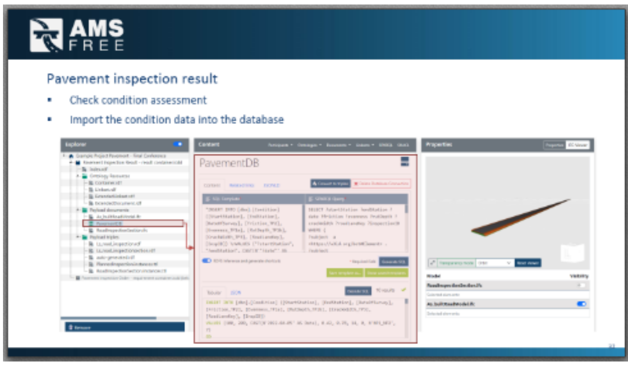

AMS FREE
Bridge maintenance – Result
Asset Manager
Construction team

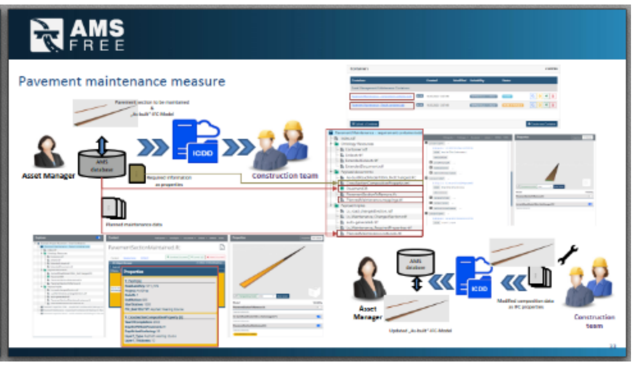

AMS FREE
Demonstration on the result container for bridge maintenance
Overview of new construction elements on the model
Check results of construction using a query
Import the changed elements data into the database
Link Details

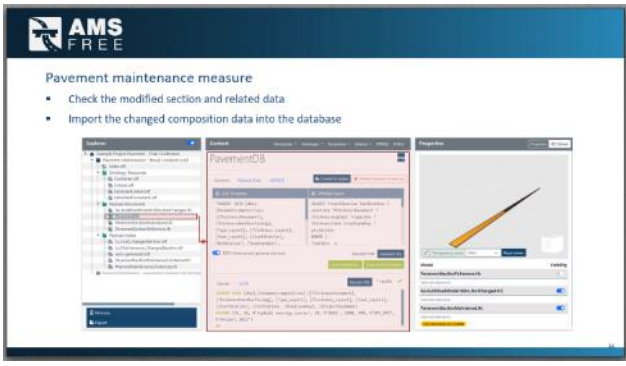

AMS FREE
Conclusion of use cases for bridge
The technical approach to data preparation and exchange :
Required information as ontology-based data collected by a contractor
Changed model provided by a contractor
Necessary domain ontology provided by asset manager
As-built model provided by asset manager
Planned activities as semantic data from IAMS
06/03/22
AMSfree.eu
29

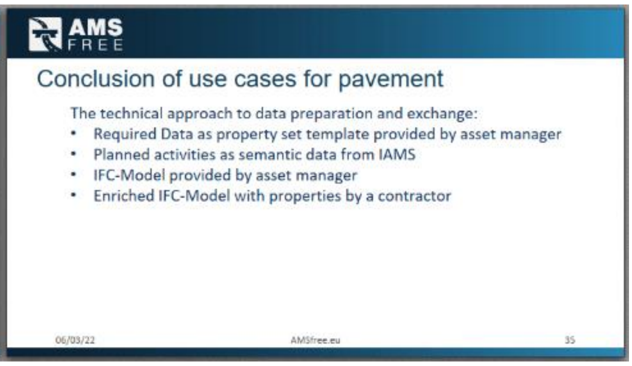

AMS FREE
Short introduction of
use cases for pavement
- the ICDDs prepared for self-testing
06/03/22
AMSfree.eu
30


AMS FREE
Pavement inspection
Asset Manager
Inspector


AMS FREE
Pavement inspection result
Check condition assessment
Import the condition data into the database
PavementDB


AMS FREE
Pavement maintenance measure
Asset Manager
Construction team


AMS FREE
Pavement maintenance measure
Check the modified section and related data
Import the changed composition data into the database
PavementDB


AMS FREE
Conclusion of use cases for pavement
The technical approach to data preparation and exchange:
Required Data as property set template provided by asset manager
Planned activities as semantic data from IAMS
IFC-Model provided by asset manager
Enriched IFC-Model with properties by a contractor
06/03/22
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AMS FREE
Q&A
30/05/22
AMSfree.eu
36


AMS FREE
THANK YOU FOR YOUR ATTENTION!

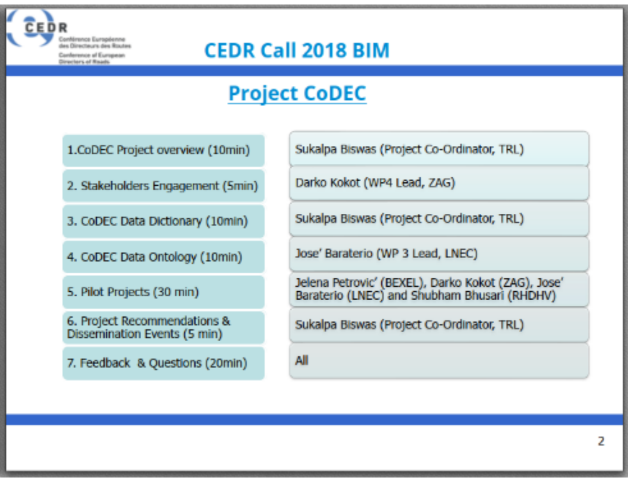
A.3.3 Use Case posters

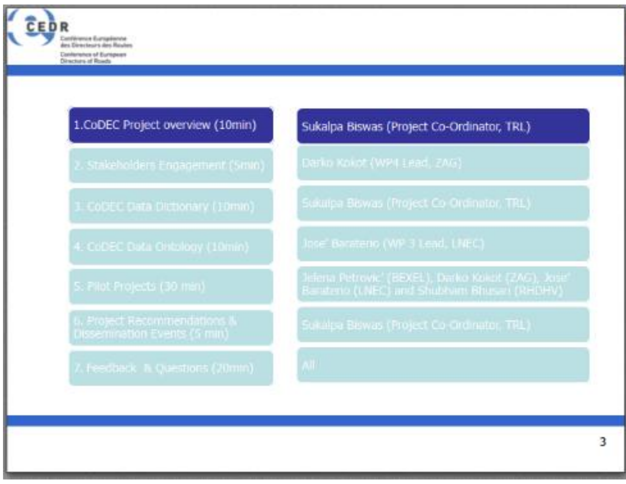

ICDD Platform
AMS FREE
Use Case 2 – Maintenance Plan
Data Collection by Using ICDD
Exchange and Exploitation of Data from Asset Management Systems using Vendor-free Format
The aim of the AMSfree project is to develop a new approach based on information containers to combine asset management systems and BIM. Therefore, the processes and procedures existing within asset management systems as well as the related data flows were analysed and described by using process and data flow models. Three typical use cases were identified, and their data exchange was described. The interoperability and the connection with already existing databases or information systems are considered. Based on the example of a road section and a bridge, the consistency of the BIM concept and the implementation of rights of use are demonstrated. It is shown how existing national data formats (e.g., OKSTRA) for the management of road and bridges are linked to the IFC format during the entire life span. The approach differentiates between data that is directly contained in BIM and data that is linked to external databases.
Activities for Maintenance Plan
The asset manager provides data on the results of the condition survey and assessment. These information are handed over to the team which is responsible for the detailed preparation of the tender.
The following data are required for this use case by using BIM:
• the IFC model
• the virtual layer with condition assessment or bridge element linked with condition data can be used for the maintenance plan
• the defined bridge/road elements to be maintained
To facilitate the recognition of mapping between the IFC model and the distributed data, and to facilitate the data exchange between the different participants, the ICDD Prototype supplies a solution to collect the data linked in a whole package as a container named ICDD.
In order to define the type and amount of maintenance interventions by the tender preparation team, the results of the condition survey and assessment are queried and output via a SPARQL query from the asset manager using the ICDD container. The data can now be used outside the model.
IFC Model
AMS Database
ICDD
Asset Manager
Tender Preparation Team
In addition to the general 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.
Once the maintenance intervention plan is finished, the results can be given back from the external contractor to the asset manager by using the ICDD container.
Updated IFC Model
AMS Database
ICDD
Asset Manager
Tender Preparation Team
The asset manager can review the results of the detailed maintenance planning on the ICDD prototype. With defined queries, one can access the specified data for:
• type of maintenance measure
• timeframe
• estimated costs
• cause for maintenance activity
Realization of the Data Collection and Exchange with the ICDD Prototype
Screenshots show the user interface for:
1. Open or create a project
2. Form for connecting an existing database
3. Mapping rules as upload document in container
4. Container copy, download and upload
5. Uploaded maintenance plan related to the IFC element
6. Filter data with SPARQL Query
Set the SQL Template
Generate SQL query and import the data into database
Prototype:
https://icdd.vm.rub.de/amsfree
Project Website:
http://www.amsfree.eu
Contact:
icdd-plattform@ruhr-uni-bochum.de
HKA
INGEO
RUB

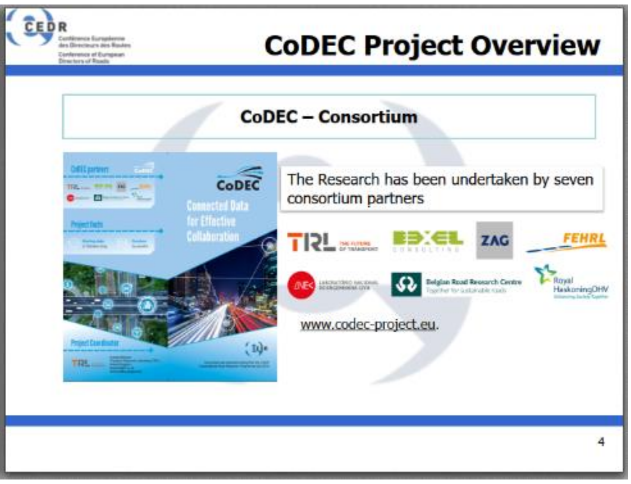

ICDD Platform
AMS FREE
Use Case 3 – Maintenance Measures
Connection with Existing Databases by Using ICDD
Exchange and Exploitation of Data from Asset Management Systems using Vendor-free Format
The aim of the AMSfree project is to develop a new approach based on information containers to combine asset management systems and BIM. Therefore, the processes and procedures existing within asset management systems as well as the related data flows were analysed and described by using process and data flow models. Three typical use cases were identified, and their data exchange was described. The interoperability and the connection with already existing databases or information systems are considered. Based on the example of a road section and a bridge, the consistency of the BIM concept and the implementation of rights of use are demonstrated. It is shown how existing national data formats (e.g., OKSTRA) for the management of road and bridges are linked to the IFC format during the entire life span. The approach differentiates between data that is directly contained in BIM and data that is linked to external databases.
Activities for Maintenance Measures
The asset manager provides the contractor with a planning model for the maintenance measures to be carried out. For this purpose, he provides the IFC model with the elements to be replaced and their associated requirements on material properties.
The following data is required for the update in order to implement this use case in BIM:
• the IFC model
• the replaced elements after implementation of the measure
• the updated material properties of the elements
To facilitate the recognition of mapping between the IFC model and the distributed data, and to facilitate the data exchange between the different participants, the ICDD Prototype supplies a solution to collect the data linked in a whole package as a container named ICDD.
Once the IFC elements are defined to be maintained, the prepared data can be delivered from the asset manager to the construction team using the ICDD container.
IFC Model
AMS Database
ICDD
Asset Manager
Construction Team
The construction team accesses the asset manager's prepared documents via the information container. The team uses the IFC model created by the asset manager as a basis for documenting the construction work achieved (scope of measures, installation quality, etc.).
Once the team has integrated all the data relevant to the construction process into the IFC model, the updated data can be transferred to the asset manager using the information container.
AMS Database
Updated As-built IFC Model
ICDD
Elaboration As-built IFC Model
Asset Manager
Construction Team
As a result, the asset manager can access both the updated IFC model and all the associated updated material data and integrate it into its existing asset management database.
Realization of the Data Collection and Exchange with the ICDD Prototype
Screenshots show the user interface for:
1. Open or create a project
2. Form for connecting an existing database
3. Mapping rules as upload document in container
4. Container copy, download and upload
5. The defined IFC elements to be maintained
6. The updated IFC model
HKA
INGEO
RUB
Prototype:
https://icdd.vm.rub.de/amsfree
Project Website:
http://www.amsfree.eu
Contact:
icdd-plattform@ruhr-uni-bochum.de

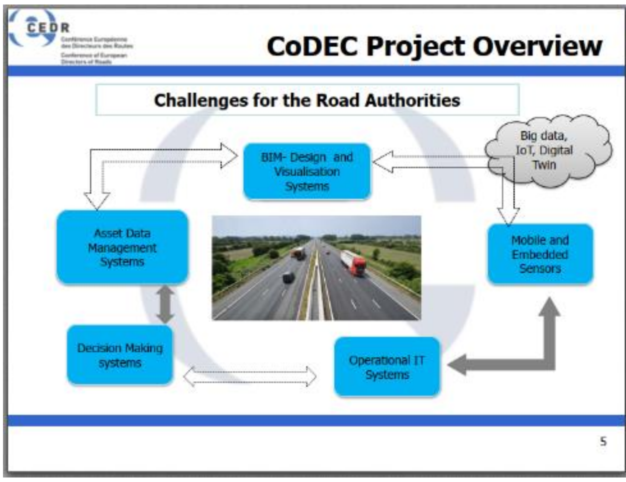
A.4 CoDEC project presentations

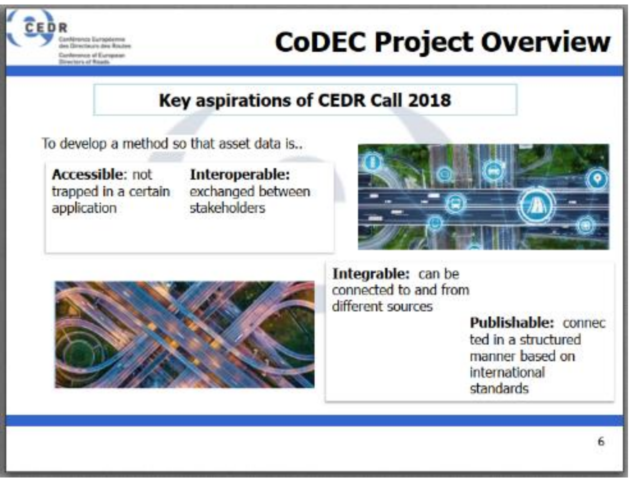
A.4.1 *Day 1 presentations*

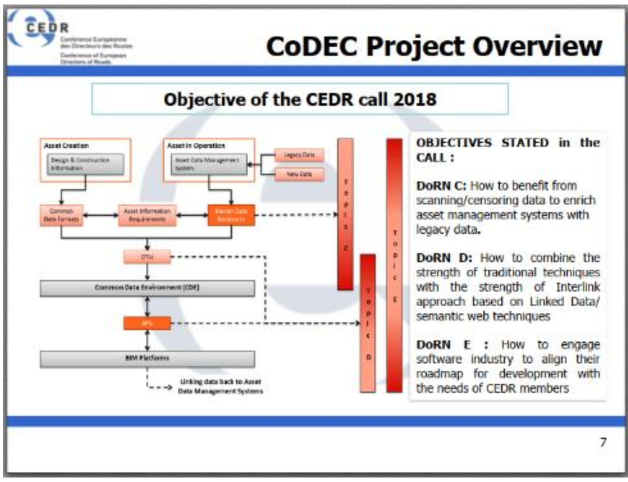


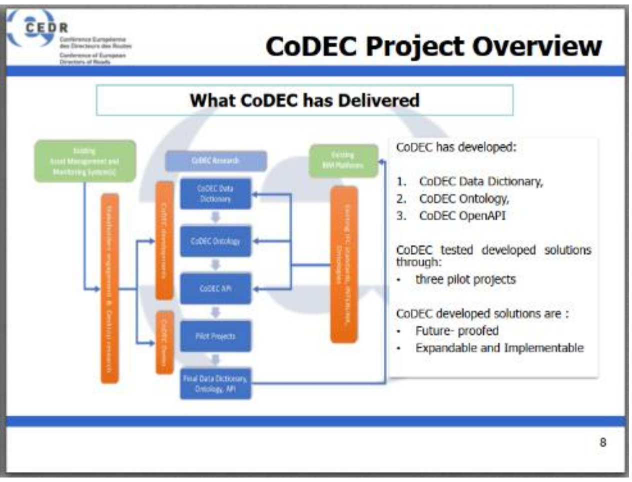


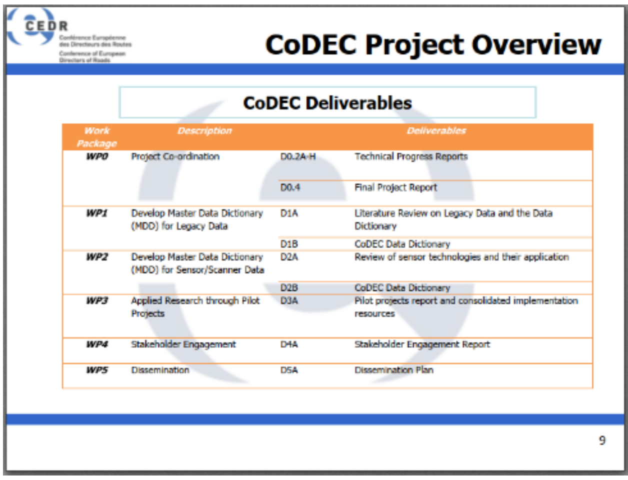


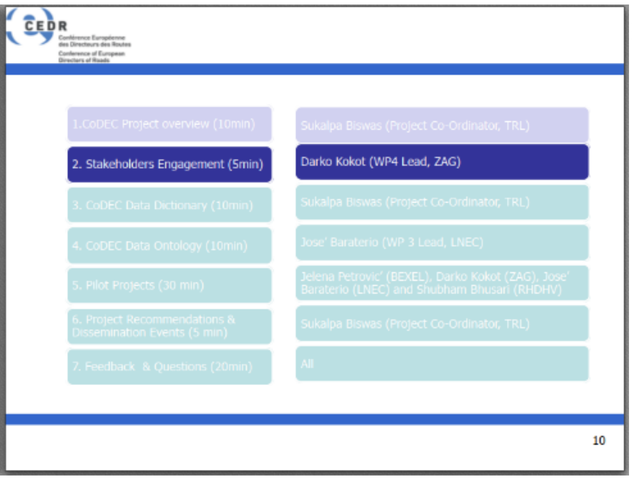


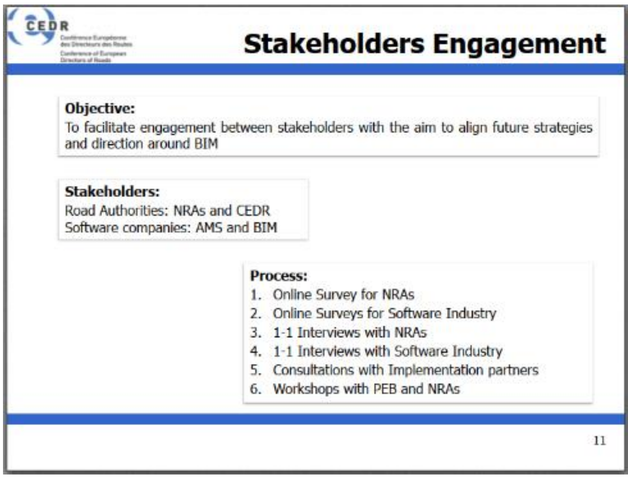


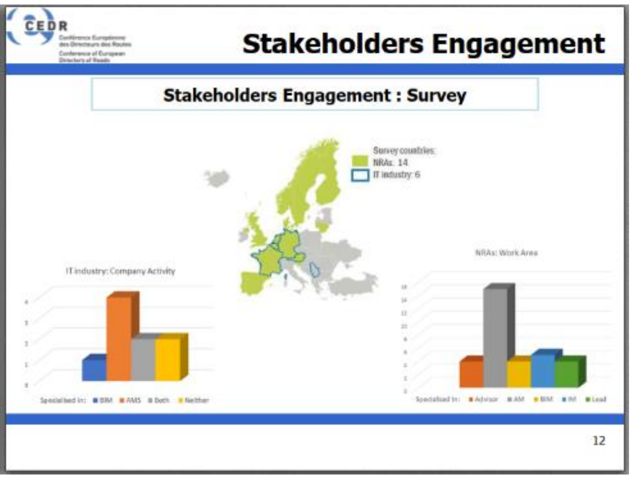

CoDEC Project Overview
Objective of the CEDR call 2018
OBJECTIVES STATED in the CALL :
DoRN C: How to benefit from scanning/censoring data to enrich asset management systems with legacy data.
DoRN D: How to combine the strength of traditional techniques with the strength of Interlink approach based on Linked Data/ semantic web techniques
DoRN E : How to engage software industry to align their roadmap for development with the needs of CEDR members
7

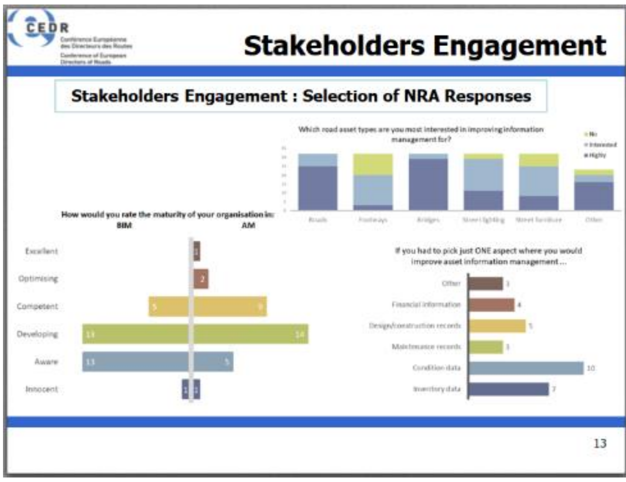

CoDEC Project Overview
What CoDEC has Delivered
CoDEC has developed:
1. CoDEC Data Dictionary,
2. CoDEC Ontology,
3. CoDEC OpenAPI
CoDEC tested developed solutions through:
• three pilot projects
CoDEC developed solutions are :
• Future- proofed
• Expandable and Implementable
8


CoDEC Project Overview
CoDEC Deliverables
Work Package | Description | Deliverables
WP0 | Project Co-ordination | D0.2A-H | Technical Progress Reports
D0.4 | Final Project Report
WP1 | Develop Master Data Dictionary (MDD) for Legacy Data | D1A | Literature Review on Legacy Data and the Data Dictionary
D1B | CoDEC Data Dictionary
WP2 | Develop Master Data Dictionary (MDD) for Sensor/Scanner Data | D2A | Review of sensor technologies and their application
D2B | CoDEC Data Dictionary
WP3 | Applied Research through Pilot Projects | D3A | Pilot projects report and consolidated implementation resources
WP4 | Stakeholder Engagement | D4A | Stakeholder Engagement Report
WP5 | Dissemination | D5A | Dissemination Plan
9

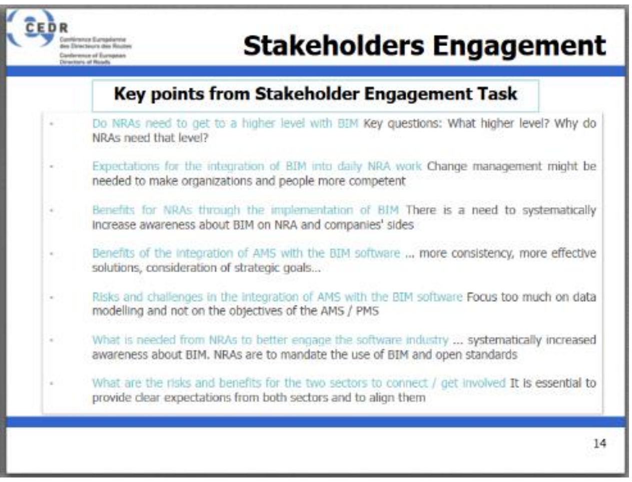

1.CoDEC Project overview (10min)
Sukalpa Biswas (Project Co-Ordinator, TRL)
2. Stakeholders Engagement (5min)
Darko Kokot (WP4 Lead, ZAG)
3. CoDEC Data Dictionary (10min)
Sukalpa Biswas (Project Co-Ordinator, TRL)
4. CoDEC Data Ontology (10min)
Jose' Barateiro (WP 3 Lead, LNEC)
5. Pilot Projects (30 min)
Jelena Petrovic' (BEXEL), Darko Kokot (ZAG), Jose' Barateiro (LNEC) and Shubham Bhusari (RHDHV)
6. Project Recommendations & Dissemination Events (5 min)
Sukalpa Biswas (Project Co-Ordinator, TRL)
7. Feedback & Questions (20min)
All
10


Stakeholders Engagement
Objective:
To facilitate engagement between stakeholders with the aim to align future strategies and direction around BIM
Stakeholders:
Road Authorities: NRAs and CEDR
Software companies: AMS and BIM
Process:
1. Online Survey for NRAs
2. Online Surveys for Software Industry
3. 1-1 Interviews with NRAs
4. 1-1 Interviews with Software Industry
5. Consultations with Implementation partners
6. Workshops with PEB and NRAs
11

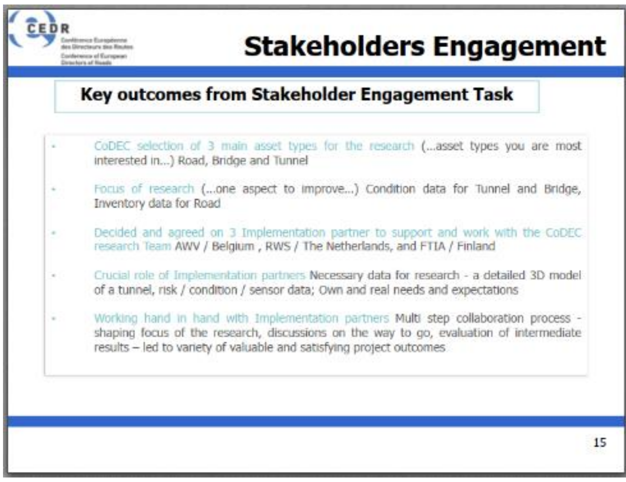

Stakeholders Engagement
Stakeholders Engagement : Survey
Survey countries:
NRAs: 14
IT industry: 6
IT industry: Company Activity
NRAs: Work Area
12



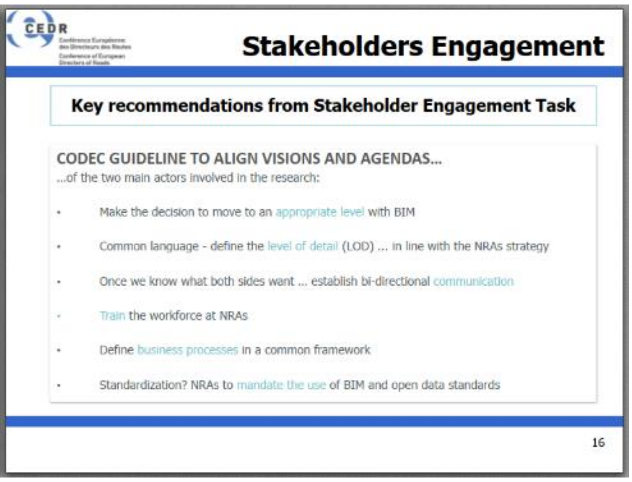
Stakeholders Engagement
Stakeholders Engagement : Selection of NRA Responses
Which road asset types are you most interested in improving information management for?
How would you rate the maturity of your organisation in: BIM AM
Excellent
Optimising
Competent
Developing
Aware
Innocent
If you had to pick just ONE aspect where you would improve asset information management…
Other
Financial information
Design/construction records
Maintenance records
Condition data
Inventory data
13



Stakeholders Engagement
Key points from Stakeholder Engagement Task
Do NRAs need to get to a higher level with BIM Key questions: What higher level? Why do NRAs need that level?
Expectations for the integration of BIM into daily NRA work Change management might be needed to make organizations and people more competent
Benefits for NRAs through the implementation of BIM There is a need to systematically increase awareness about BIM on NRA and companies' sides
Benefits of the integration of AMS with the BIM software ... more consistency, more effective solutions, consideration of strategic goals...
Risks and challenges in the integration of AMS with the BIM software Focus too much on data modelling and not on the objectives of the AMS / PMS
What is needed from NRAs to better engage the software industry ... systematically increased awareness about BIM. NRAs are to mandate the use of BIM and open standards
What are the risks and benefits for the two sectors to connect / get involved It is essential to provide clear expectations from both sectors and to align them
14



Stakeholders Engagement
Key outcomes from Stakeholder Engagement Task
CoDEC selection of 3 main asset types for the research (...asset types you are most interested in...) Road, Bridge and Tunnel
Focus of research (...one aspect to improve...) Condition data for Tunnel and Bridge, Inventory data for Road
Decided and agreed on 3 Implementation partner to support and work with the CoDEC research Team AWV / Belgium , RWS / The Netherlands, and FTIA / Finland
Crucial role of Implementation partners Necessary data for research - a detailed 3D model of a tunnel, risk / condition / sensor data; Own and real needs and expectations
Working hand in hand with Implementation partners Multi step collaboration process - shaping focus of the research, discussions on the way to go, evaluation of intermediate results – led to variety of valuable and satisfying project outcomes
15



Stakeholders Engagement
Key recommendations from Stakeholder Engagement Task
CODEC GUIDELINE TO ALIGN VISIONS AND AGENDAS...
...of the two main actors involved in the research:
Make the decision to move to an appropriate level with BIM
Common language - define the level of detail (LOD) ... in line with the NRAs strategy
Once we know what both sides want ... establish bi-directional communication
Train the workforce at NRAs
Define business processes in a common framework
Standardization? NRAs to mandate the use of BIM and open data standards
16

1.CoDEC Project overview (10min)
Sukalpa Biswas (Project Co-Ordinator, TRL)
2. Stakeholders Engagement (5min)
Darko Kokot (WP4 Lead, ZAG)
3. CoDEC Data Dictionary (10min)
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4. CoDEC Data Ontology (10min)
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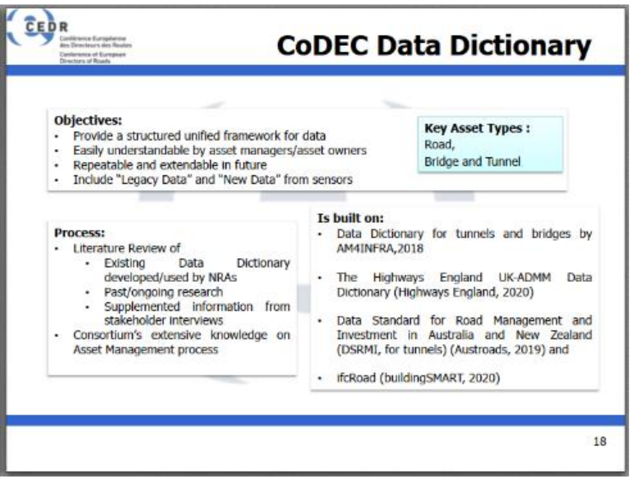
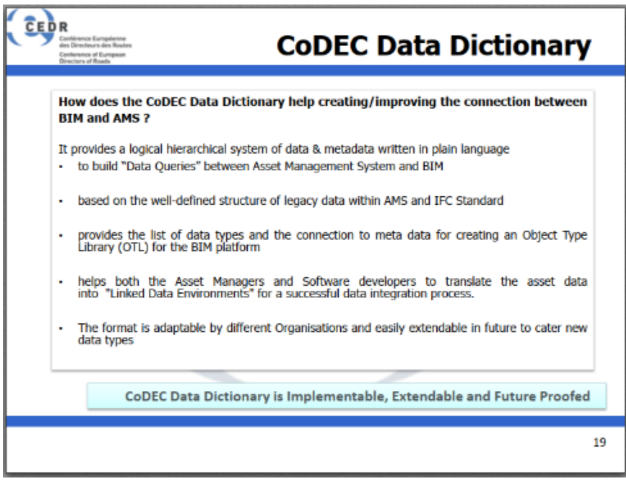
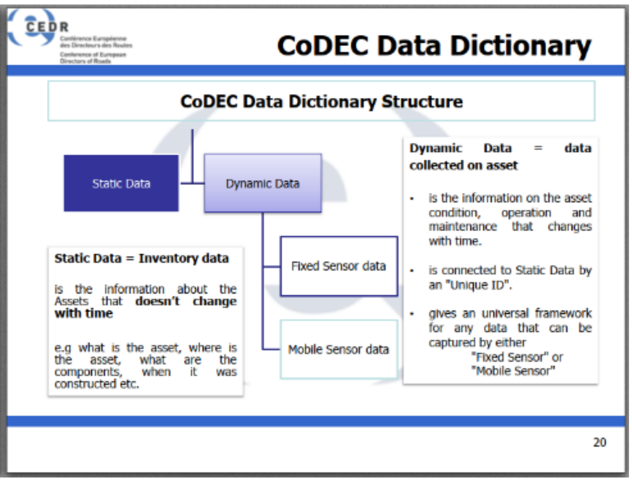
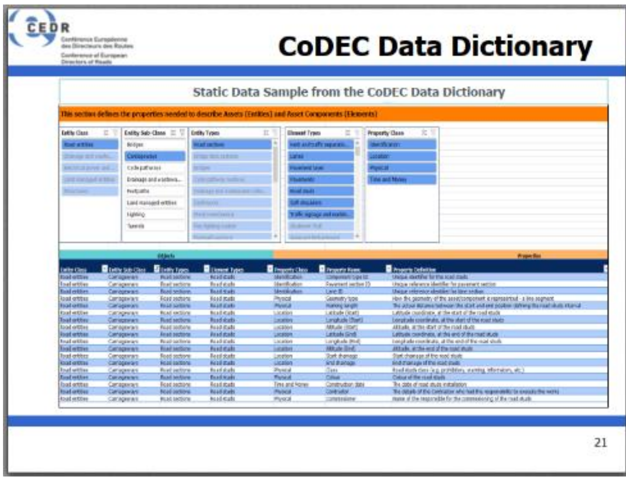
7. Feedback & Questions (20min)
All
17

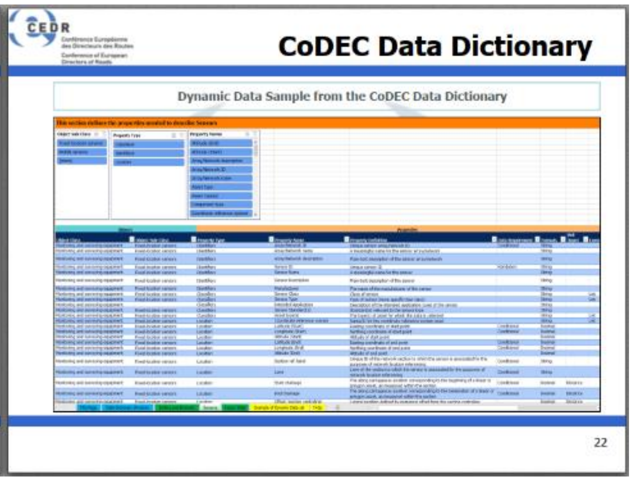


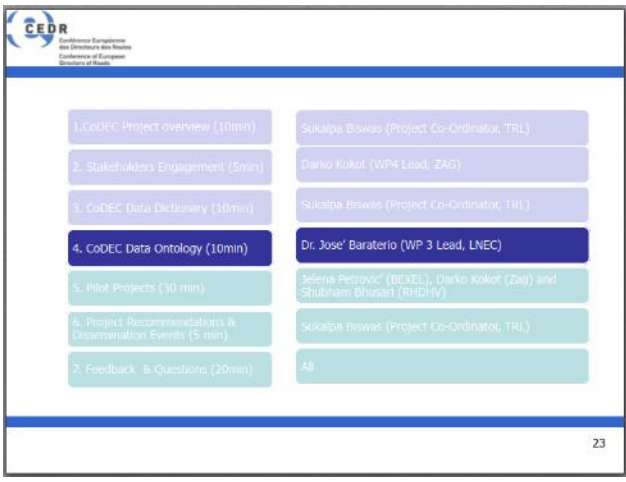
CoDEC Data Dictionary
Objectives:
Provide a structured unified framework for data
Easily understandable by asset managers/asset owners
Repeatable and extendable in future
Include "Legacy Data" and "New Data" from sensors
Key Asset Types :
Road,
Bridge and Tunnel
Process:
Literature Review of
Existing Data Dictionary developed/used by NRAs
Past/ongoing research
Supplemented information from stakeholder interviews
Consortium's extensive knowledge on Asset Management process
Is built on:
Data Dictionary for tunnels and bridges by AM4INFRA,2018
The Highways England UK-ADMM Data Dictionary (Highways England, 2020)
Data Standard for Road Management and Investment in Australia and New Zealand (DSRMI, for tunnels) (Austroads, 2019) and
ifcRoad (buildingSMART, 2020)
18


CoDEC Data Dictionary
How does the CoDEC Data Dictionary help creating/improving the connection between BIM and AMS ?
It provides a logical hierarchical system of data & metadata written in plain language
• to build "Data Queries" between Asset Management System and BIM
• based on the well-defined structure of legacy data within AMS and IFC Standard
• provides the list of data types and the connection to meta data for creating an Object Type Library (OTL) for the BIM platform
• helps both the Asset Managers and Software developers to translate the asset data into "Linked Data Environments" for a successful data integration process.
• The format is adaptable by different Organisations and easily extendable in future to cater new data types
CoDEC Data Dictionary is Implementable, Extendable and Future Proofed
19


CoDEC Data Dictionary
CoDEC Data Dictionary Structure
Static Data
Dynamic Data
Static Data = Inventory data
is the information about the Assets that doesn't change with time
e.g what is the asset, where is the asset, what are the components, when it was constructed etc.
Fixed Sensor data
Mobile Sensor data
Dynamic Data = data collected on asset
• is the information on the asset condition, operation and maintenance that changes with time.
• is connected to Static Data by an "Unique ID".
• gives an universal framework for any data that can be captured by either "Fixed Sensor" or "Mobile Sensor"
20


CoDEC Data Dictionary
Static Data Sample from the CoDEC Data Dictionary
21


CoDEC Data Dictionary
Dynamic Data Sample from the CoDEC Data Dictionary
22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4. CoDEC Data Ontology (10min)
Dr. Jose' Barateiro (WP 3 Lead, LNEC)
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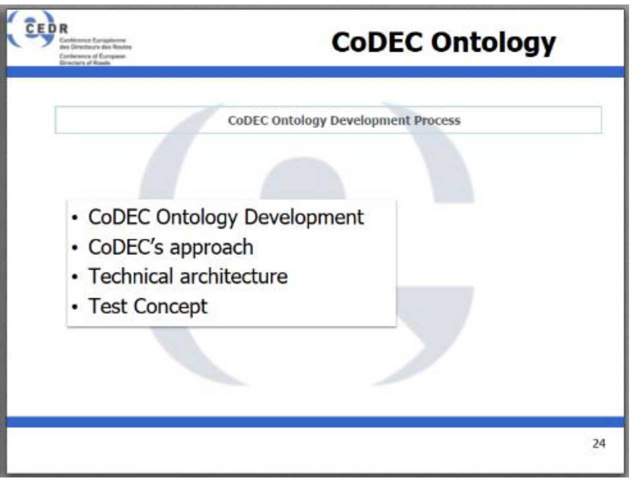
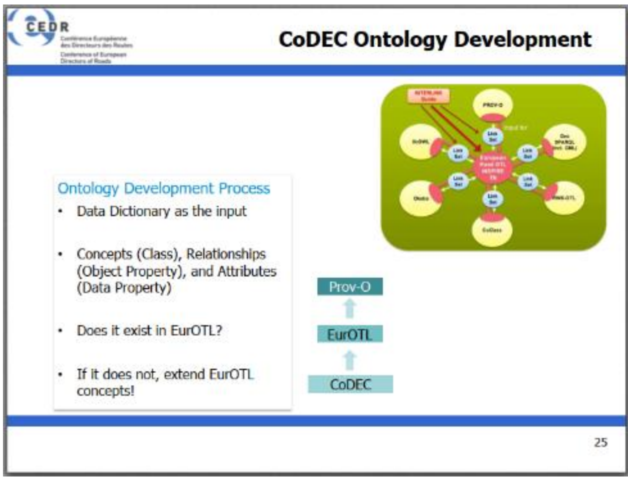
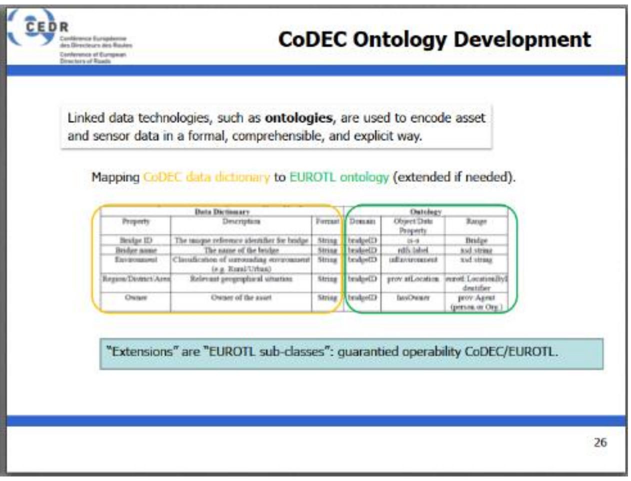
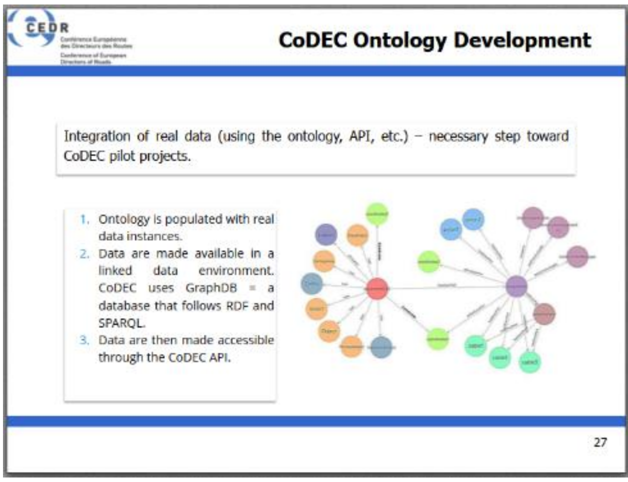
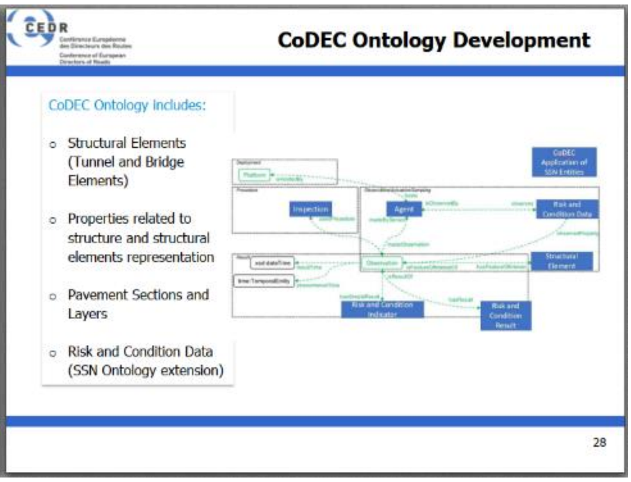
All
23

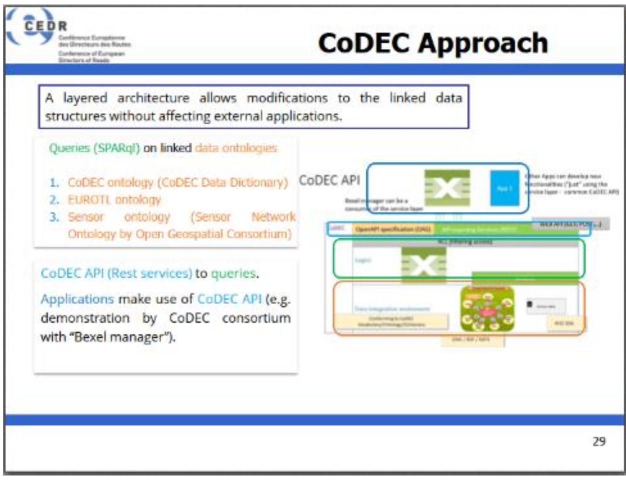

CoDEC Ontology
CoDEC Ontology Development Process
• CoDEC Ontology Development
• CoDEC's approach
• Technical architecture
• Test Concept
24

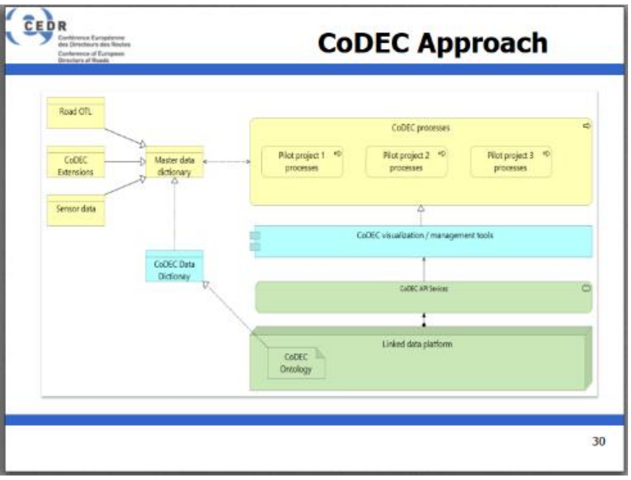

CoDEC Ontology Development
Ontology Development Process
Data Dictionary as the input
Concepts (Class), Relationships (Object Property), and Attributes (Data Property)
Does it exist in EurOTL?
If it does not, extend EurOTL concepts!
Prov-O
EurOTL
CoDEC
25

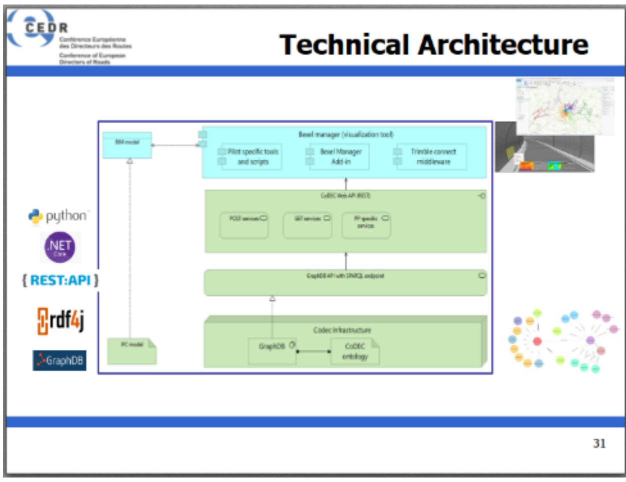

CoDEC Ontology Development
Linked data technologies, such as ontologies, are used to encode asset and sensor data in a formal, comprehensible, and explicit way.
Mapping CoDEC data dictionary to EUROTL ontology (extended if needed).
"Extensions" are "EUROTL sub-classes": guarantied operability CoDEC/EUROTL.
26

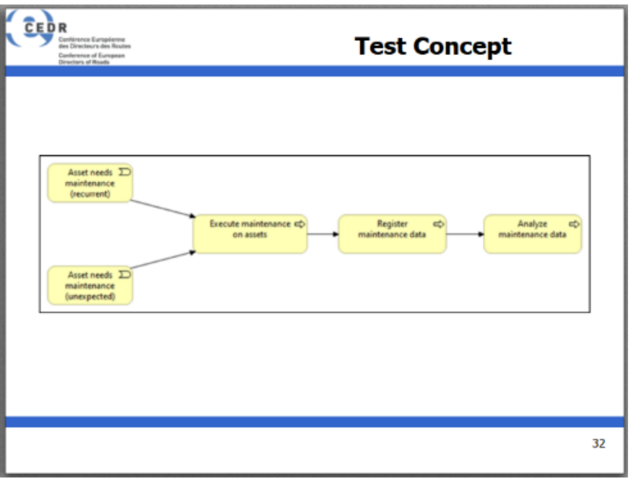

CoDEC Ontology Development
Integration of real data (using the ontology, API, etc.) – necessary step toward CoDEC pilot projects.
1. Ontology is populated with real data instances.
2. Data are made available in a linked data environment. CoDEC uses GraphDB = a database that follows RDF and SPARQL.
3. Data are then made accessible through the CoDEC API.
27

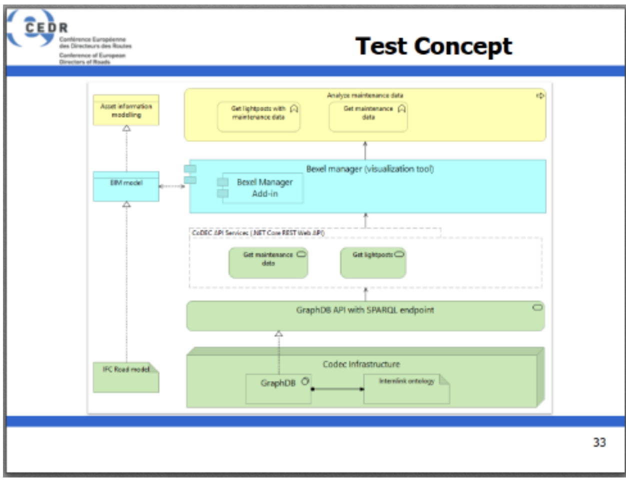

CoDEC Ontology Development
CoDEC Ontology includes:
Structural Elements (Tunnel and Bridge Elements)
Properties related to structure and structural elements representation
Pavement Sections and Layers
Risk and Condition Data (SSN Ontology extension)
28

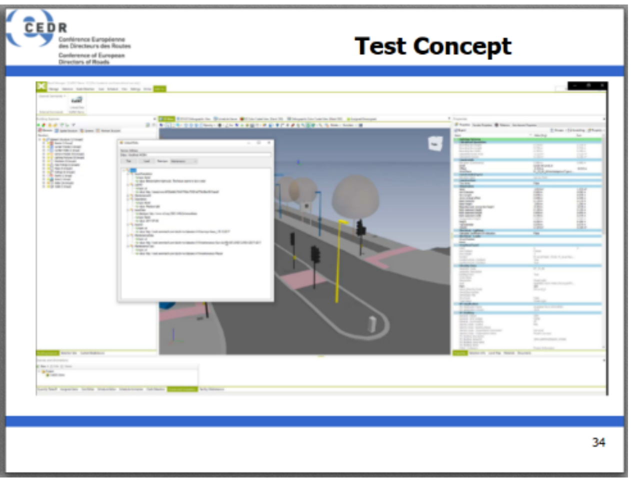

CoDEC Approach
A layered architecture allows modifications to the linked data structures without affecting external applications.
Queries (SPARql) on linked data ontologies
1. CoDEC ontology (CoDEC Data Dictionary)
2. EUROTL ontology
3. Sensor ontology (Sensor Network Ontology by Open Geospatial Consortium)
CoDEC API (Rest services) to queries.
Applications make use of CoDEC API (e.g. demonstration by CoDEC consortium with "Bexel manager").
CoDEC API
29

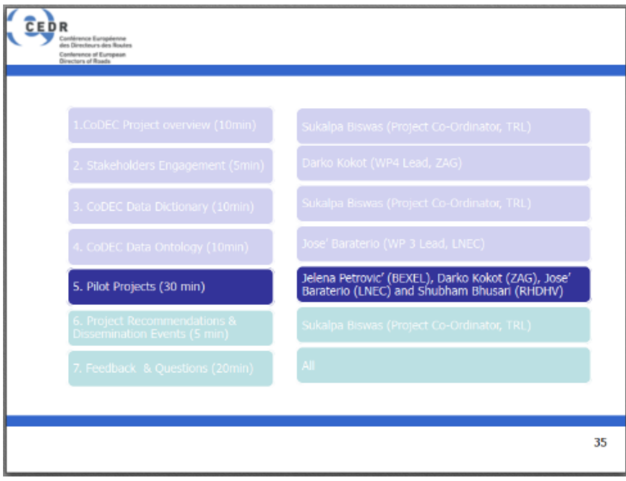

CoDEC Approach
Road OTL
CoDEC Extensions
Sensor data
Master data dictionary
CoDEC processes
Pilot project 1 processes
Pilot project 2 processes
Pilot project 3 processes
CoDEC visualization / management tools
CoDEC API Sevices
CoDEC Data Dictionary
Linked data platform
CoDEC Ontology
30

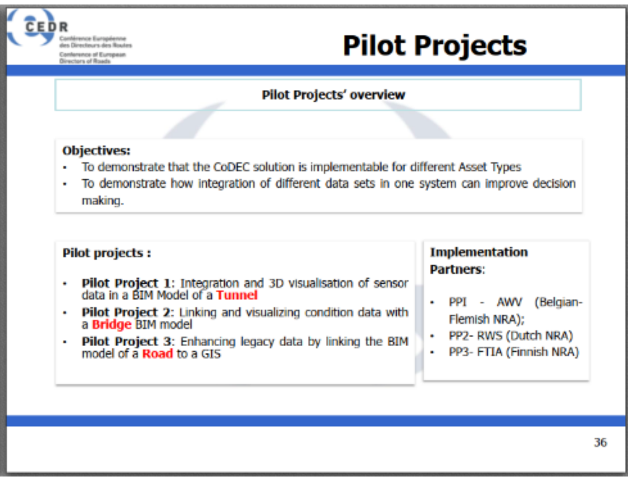

Technical Architecture
python
.NET
{ REST:API }
rdf4j
GraphDB
31

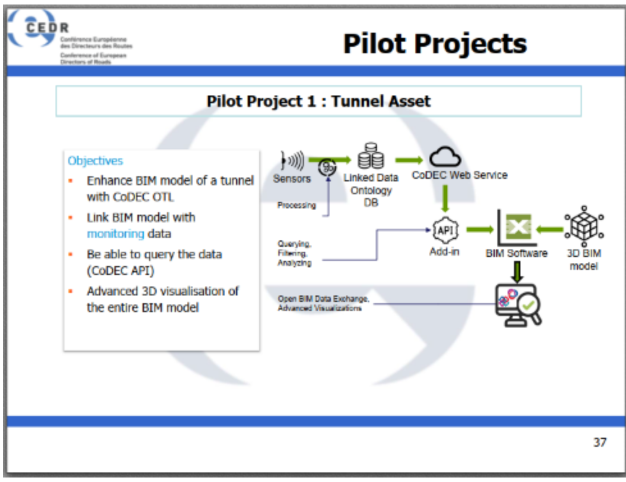

Test Concept
Asset needs maintenance (recurrent)
Asset needs maintenance (unexpected)
Execute maintenance on assets
Register maintenance data
Analyze maintenance data
32

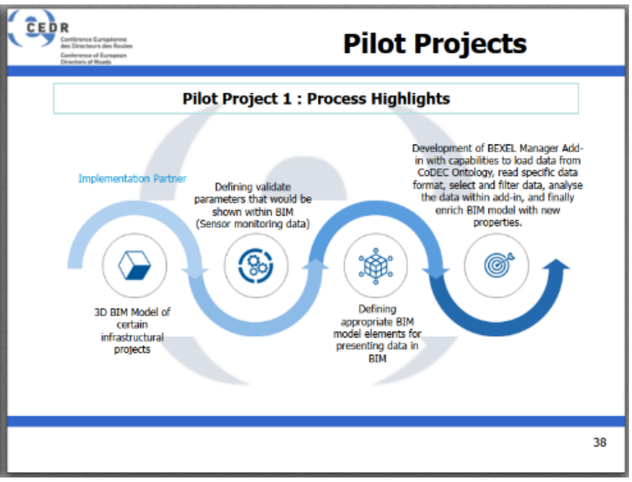

Test Concept
Asset information modelling
Analyze maintenance data
Get lightposts with maintenance data
Get maintenance data
BIM model
Bexel manager (visualization tool)
Bexel Manager Add-in
CoDEC API Services (.NET Core REST Web API)
Get maintenance data
Get lightposts
GraphDB API with SPARQL endpoint
IFC Road model
Codec Infrastructure
GraphDB
Interlink ontology
33

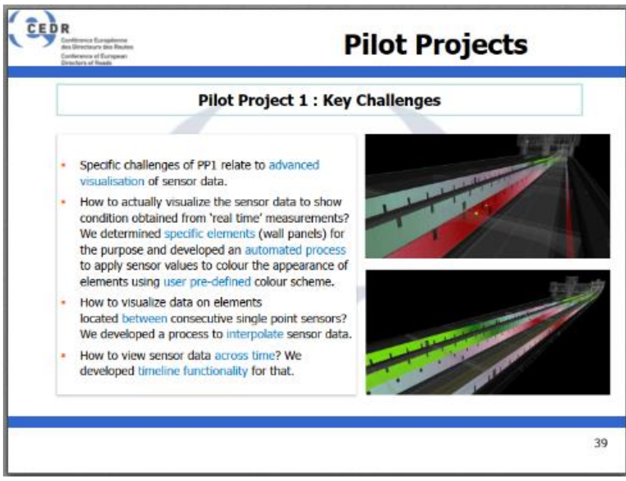

Test Concept
34

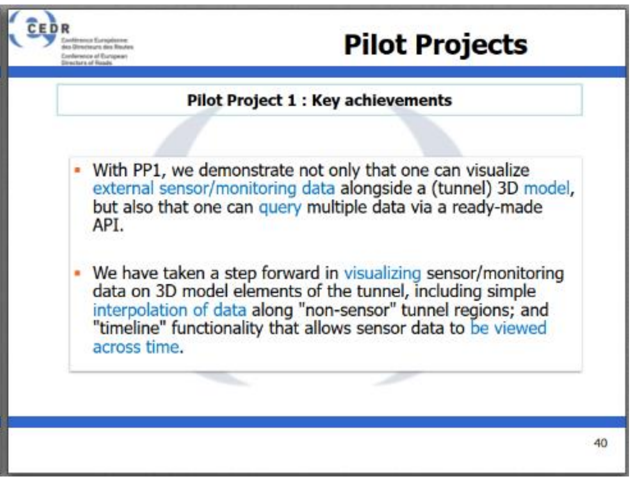

1.CoDEC Project overview (10min)
Sukalpa Biswas (Project Co-Ordinator, TRL)
2. Stakeholders Engagement (5min)
Darko Kokot (WP4 Lead, ZAG)
3. CoDEC Data Dictionary (10min)
Sukalpa Biswas (Project Co-Ordinator, TRL)
4. CoDEC Data Ontology (10min)
Jose' Baraterio (WP 3 Lead, LNEC)
5. Pilot Projects (30 min)
Jelena Petrovic' (BEXEL), Darko Kokot (ZAG), Jose' Baraterio (LNEC) and Shubham Bhusari (RHDHV)
6. Project Recommendations & Dissemination Events (5 min)
Sukalpa Biswas (Project Co-Ordinator, TRL)
7. Feedback & Questions (20min)
All
35

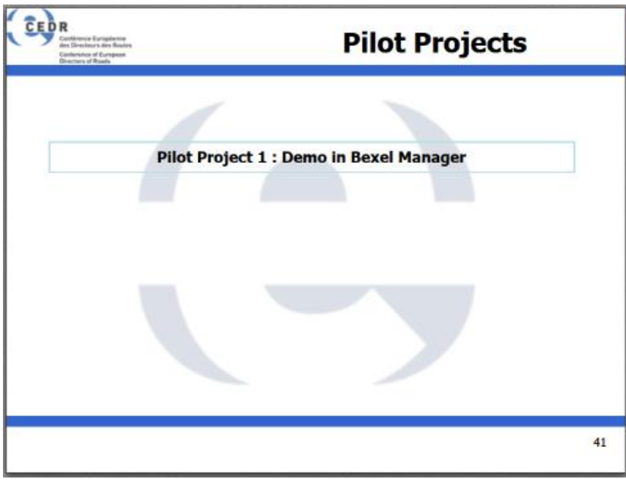

Pilot Projects
Pilot Projects' overview
Objectives:
To demonstrate that the CoDEC solution is implementable for different Asset Types
To demonstrate how integration of different data sets in one system can improve decision making.
Pilot projects :
Pilot Project 1: Integration and 3D visualisation of sensor data in a BIM Model of a Tunnel
Pilot Project 2: Linking and visualizing condition data with a Bridge BIM model
Pilot Project 3: Enhancing legacy data by linking the BIM model of a Road to a GIS
Implementation Partners:
PP1 - AWV (Belgian-Flemish NRA);
PP2- RWS (Dutch NRA)
PP3- FTIA (Finnish NRA)
36

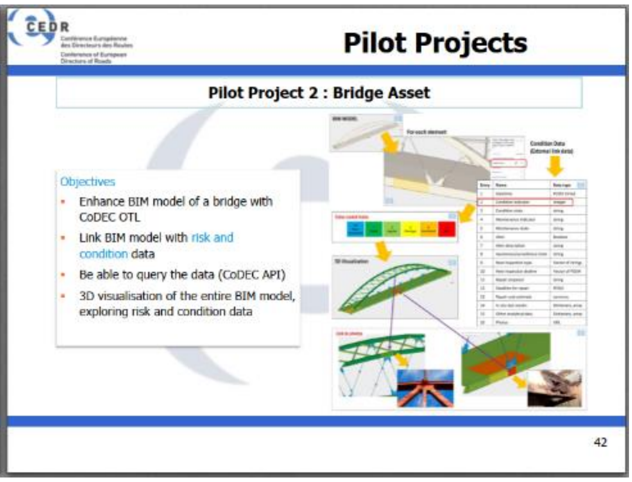

Pilot Projects
Pilot Project 1 : Tunnel Asset
Objectives
Enhance BIM model of a tunnel with CoDEC OTL
Link BIM model with monitoring data
Be able to query the data (CoDEC API)
Advanced 3D visualisation of the entire BIM model
Sensors
Linked Data Ontology DB
CoDEC Web Service
Processing
Querying, Filtering, Analyzing
API
Add-in
BIM Software
3D BIM model
Open BIM Data Exchange, Advanced Visualizations
37

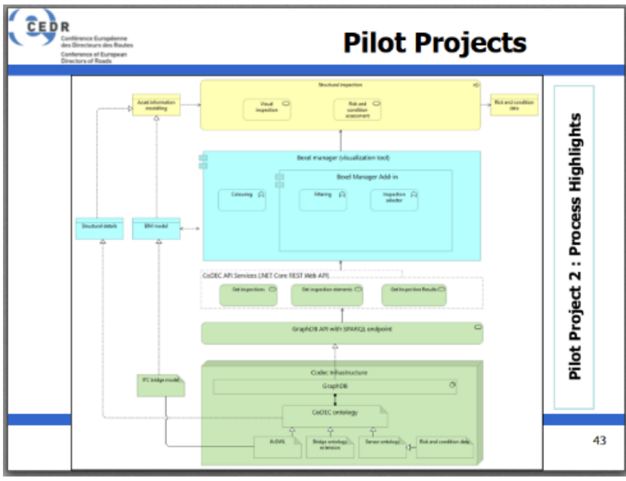

Pilot Projects
Pilot Project 1 : Process Highlights
Implementation Partner
3D BIM Model of certain infrastructural projects
Defining validate parameters that would be shown within BIM (Sensor monitoring data)
Defining appropriate BIM model elements for presenting data in BIM
Development of BEXEL Manager Add-in with capabilities to load data from CoDEC Ontology, read specific data format, select and filter data, analyse the data within add-in, and finally enrich BIM model with new properties.
38

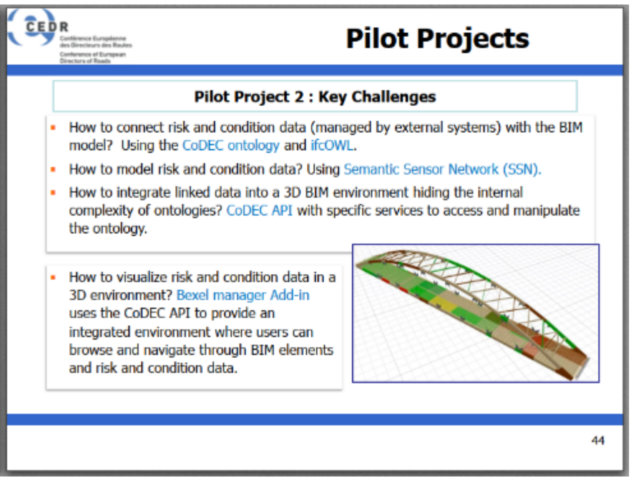

Pilot Projects
Pilot Project 1 : Key Challenges
Specific challenges of PP1 relate to advanced visualisation of sensor data.
How to actually visualize the sensor data to show condition obtained from 'real time' measurements? We determined specific elements (wall panels) for the purpose and developed an automated process to apply sensor values to colour the appearance of elements using user pre-defined colour scheme.
How to visualize data on elements located between consecutive single point sensors? We developed a process to interpolate sensor data.
How to view sensor data across time? We developed timeline functionality for that.
39

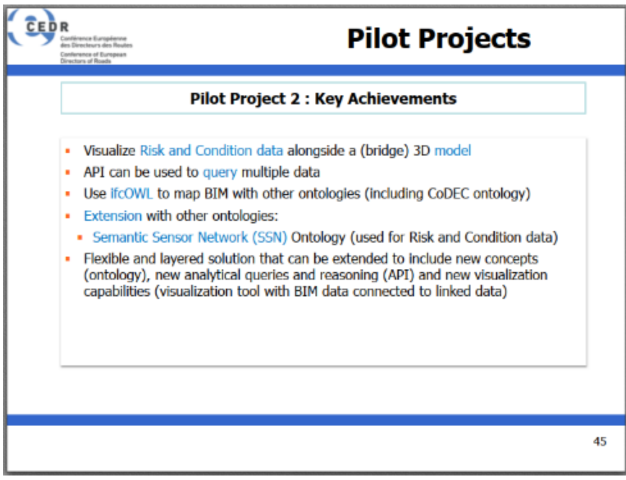

Pilot Projects
Pilot Project 1 : Key achievements
With PP1, we demonstrate not only that one can visualize external sensor/monitoring data alongside a (tunnel) 3D model, but also that one can query multiple data via a ready-made API.
We have taken a step forward in visualizing sensor/monitoring data on 3D model elements of the tunnel, including simple interpolation of data along "non-sensor" tunnel regions; and "timeline" functionality that allows sensor data to be viewed across time.
40

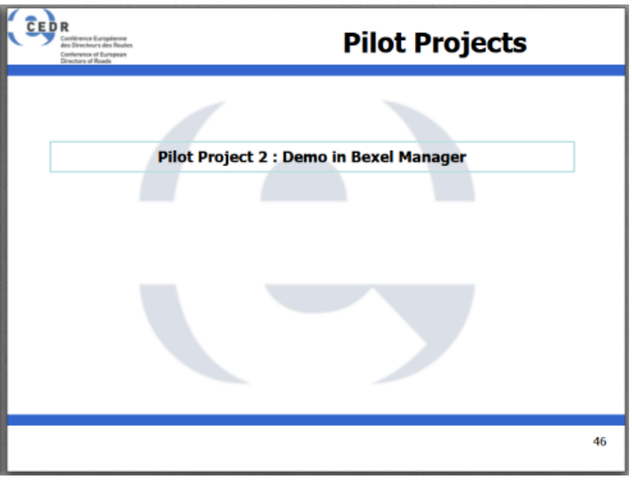

Pilot Projects
Pilot Project 1 : Demo in Bexel Manager
41

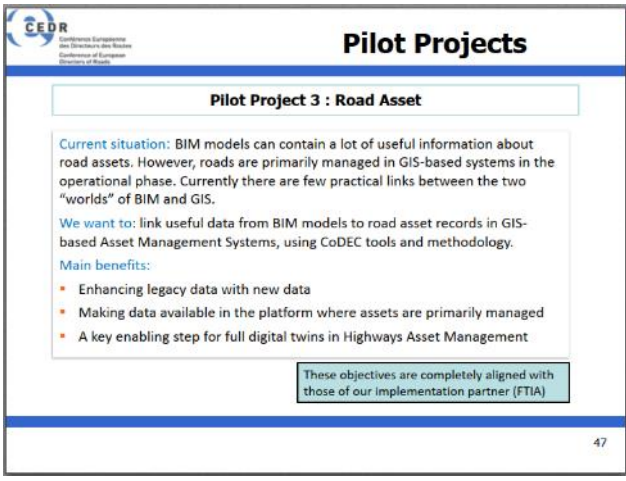

Pilot Projects
Pilot Project 2 : Bridge Asset
Objectives
Enhance BIM model of a bridge with CoDEC OTL
Link BIM model with risk and condition data
Be able to query the data (CoDEC API)
3D visualisation of the entire BIM model, exploring risk and condition data
42

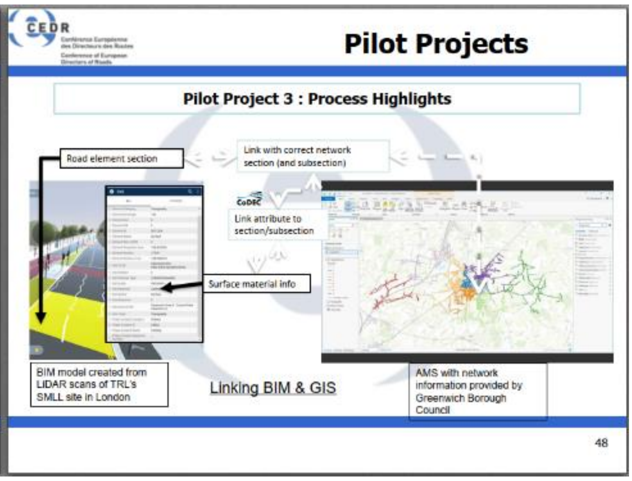

Pilot Projects
Pilot Project 2 : Process Highlights
Bexel manager (visualization tool)
Bexel Manager Add-in
CoDEC API Services (.NET Core REST Web API)
GraphDB API with SPARQL endpoint
Codec Infrastructure
GraphDB
CoDEC ontology
43

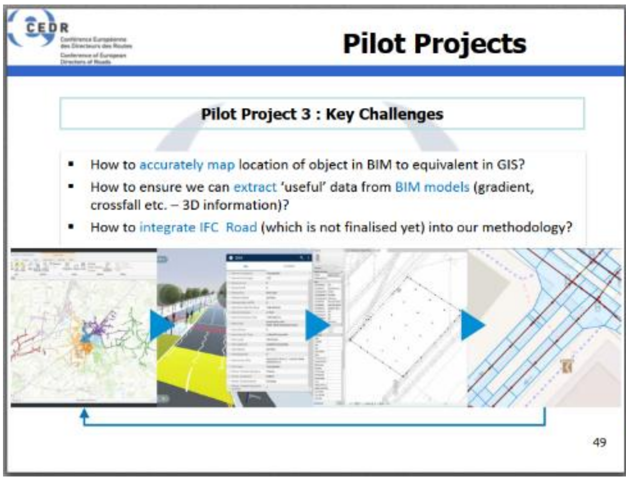

Pilot Projects
Pilot Project 2 : Key Challenges
How to connect risk and condition data (managed by external systems) with the BIM model? Using the CoDEC ontology and ifcOWL.
How to model risk and condition data? Using Semantic Sensor Network (SSN).
How to integrate linked data into a 3D BIM environment hiding the internal complexity of ontologies? CoDEC API with specific services to access and manipulate the ontology.
How to visualize risk and condition data in a 3D environment? Bexel manager Add-in uses the CoDEC API to provide an integrated environment where users can browse and navigate through BIM elements and risk and condition data.
44

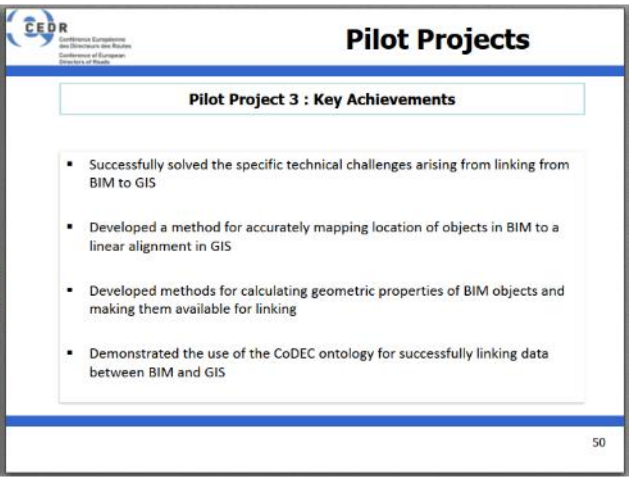

Pilot Projects
Pilot Project 2 : Key Achievements
Visualize Risk and Condition data alongside a (bridge) 3D model
API can be used to query multiple data
Use ifcOWL to map BIM with other ontologies (including CoDEC ontology)
Extension with other ontologies:
Semantic Sensor Network (SSN) Ontology (used for Risk and Condition data)
Flexible and layered solution that can be extended to include new concepts (ontology), new analytical queries and reasoning (API) and new visualization capabilities (visualization tool with BIM data connected to linked data)
45

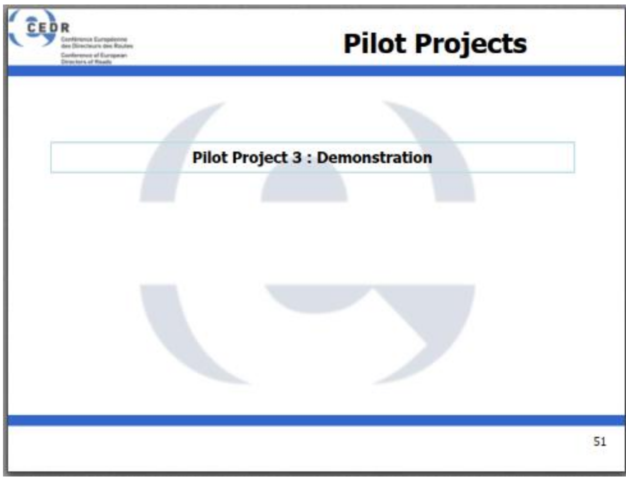

Pilot Projects
Pilot Project 2 : Demo in Bexel Manager
46

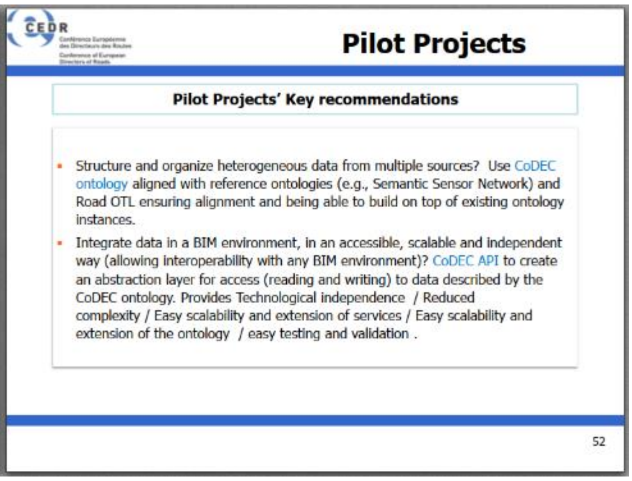

Pilot Projects
Pilot Project 3 : Road Asset
Current situation: BIM models can contain a lot of useful information about road assets. However, roads are primarily managed in GIS-based systems in the operational phase. Currently there are few practical links between the two "worlds" of BIM and GIS.
We want to: link useful data from BIM models to road asset records in GIS-based Asset Management Systems, using CoDEC tools and methodology.
Main benefits:
Enhancing legacy data with new data
Making data available in the platform where assets are primarily managed
A key enabling step for full digital twins in Highways Asset Management
These objectives are completely aligned with those of our implementation partner (FTIA)
47

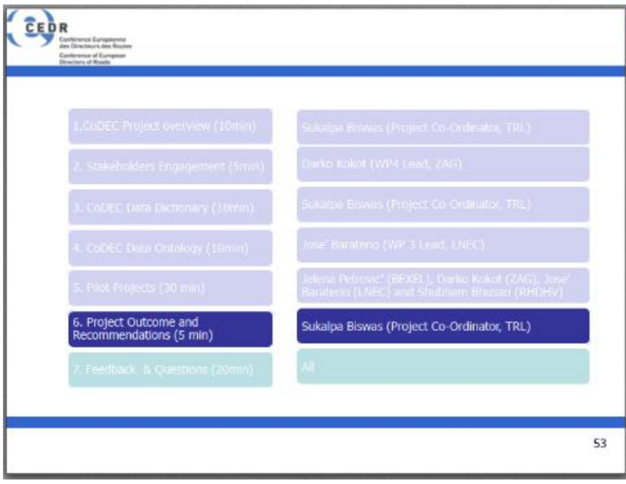

Pilot Projects
Pilot Project 3 : Process Highlights
Road element section
Link with correct network section (and subsection)
Link attribute to section/subsection
Surface material info
BIM model created from LIDAR scans of TRL's SMLL site in London
Linking BIM & GIS
AMS with network information provided by Greenwich Borough Council
48

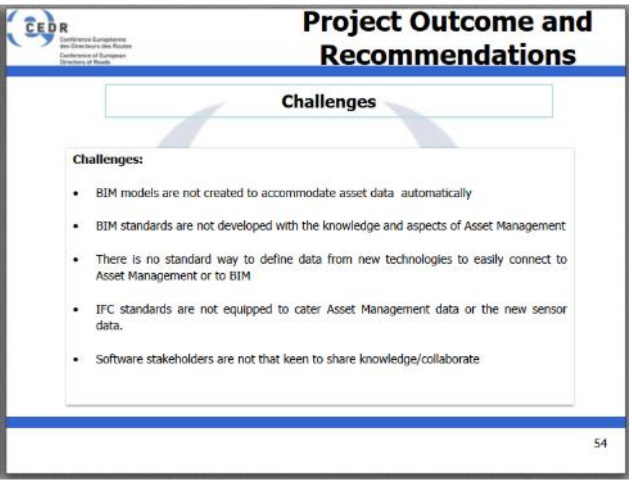

Pilot Projects
Pilot Project 3 : Key Challenges
How to accurately map location of object in BIM to equivalent in GIS?
How to ensure we can extract 'useful' data from BIM models (gradient, crossfall etc. – 3D information)?
How to integrate IFC Road (which is not finalised yet) into our methodology?
49

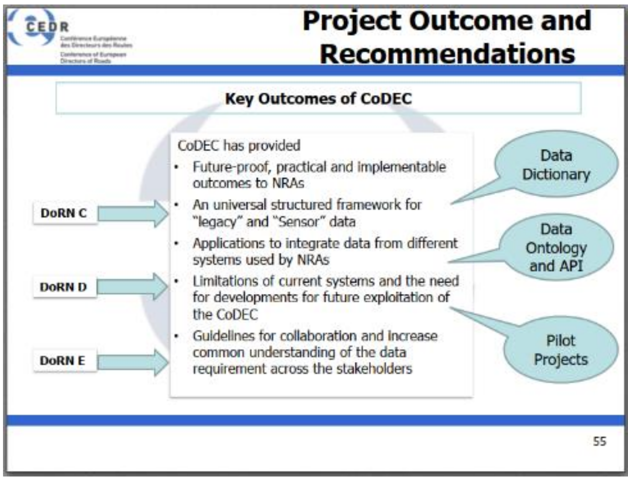

Pilot Projects
Pilot Project 3 : Key Achievements
Successfully solved the specific technical challenges arising from linking from BIM to GIS
Developed a method for accurately mapping location of objects in BIM to a linear alignment in GIS
Developed methods for calculating geometric properties of BIM objects and making them available for linking
Demonstrated the use of the CoDEC ontology for successfully linking data between BIM and GIS
50

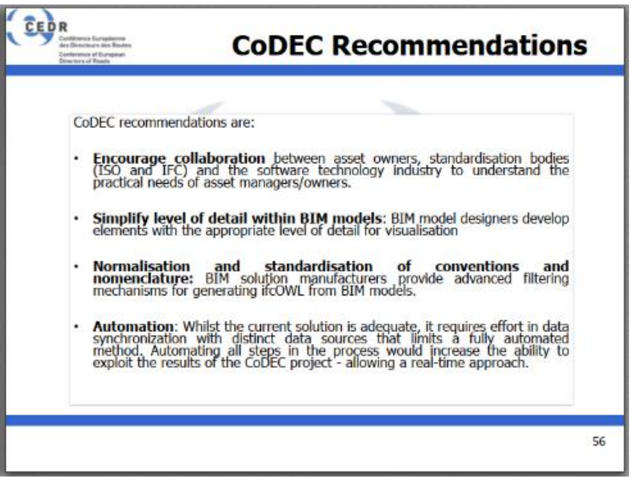

Pilot Projects
Pilot Project 3 : Demonstration
51

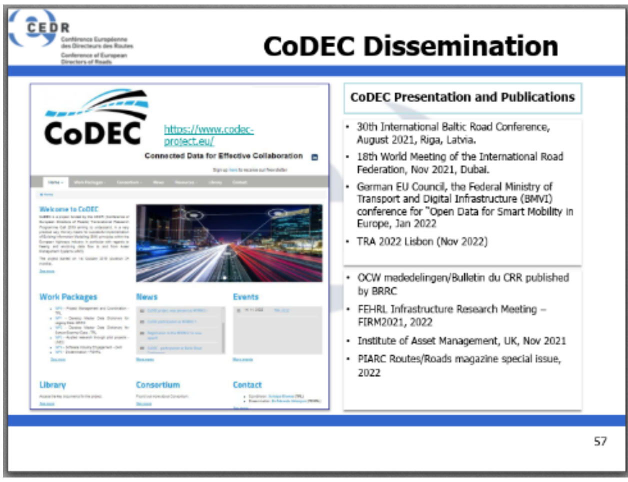

Pilot Projects
Pilot Projects' Key recommendations
Structure and organize heterogeneous data from multiple sources? Use CoDEC ontology aligned with reference ontologies (e.g., Semantic Sensor Network) and Road OTL ensuring alignment and being able to build on top of existing ontology instances.
Integrate data in a BIM environment, in an accessible, scalable and independent way (allowing interoperability with any BIM environment)? CoDEC API to create an abstraction layer for access (reading and writing) to data described by the CoDEC ontology. Provides Technological independence / Reduced complexity / Easy scalability and extension of services / Easy scalability and extension of the ontology / easy testing and validation .
52


1.CoDEC Project overview (10min)
Sukalpa Biswas (Project Co-Ordinator, TRL)
2. Stakeholders Engagement (5min)
Darko Kokot (WP4 Lead, ZAG)
3. CoDEC Data Dictionary (10min)
Sukalpa Biswas (Project Co-Ordinator, TRL)
4. CoDEC Data Ontology (10min)
Jose' Barateiro (WP 3 Lead, LNEC)
5. Pilot Projects (30 min)
6. Project Outcome and Recommendations (5 min)
Sukalpa Biswas (Project Co-Ordinator, TRL)
7. Feedback & Questions (20min)
All
53


Project Outcome and Recommendations
Challenges
Challenges:
BIM models are not created to accommodate asset data automatically
BIM standards are not developed with the knowledge and aspects of Asset Management
There is no standard way to define data from new technologies to easily connect to Asset Management or to BIM
IFC standards are not equipped to cater Asset Management data or the new sensor data.
Software stakeholders are not that keen to share knowledge/collaborate
54


Project Outcome and Recommendations
Key Outcomes of CoDEC
CoDEC has provided
Future-proof, practical and implementable outcomes to NRAs
An universal structured framework for "legacy" and "Sensor" data
Applications to integrate data from different systems used by NRAs
Limitations of current systems and the need for developments for future exploitation of the CoDEC
Guidelines for collaboration and increase common understanding of the data requirement across the stakeholders
DoRN C
DoRN D
DoRN E
Data Dictionary
Data Ontology and API
Pilot Projects
55


CoDEC Recommendations
CoDEC recommendations are:
Encourage collaboration between asset owners, standardisation bodies (ISO and IFC) and the software technology industry to understand the practical needs of asset managers/owners.
Simplify level of detail within BIM models: BIM model designers develop elements with the appropriate level of detail for visualisation
Normalisation and standardisation of conventions and nomenclature: BIM solution manufacturers provide advanced filtering mechanisms for generating ifcOWL from BIM models.
Automation: Whilst the current solution is adequate, it requires effort in data synchronization with distinct data sources that limits a fully automated method. Automating all steps in the process would increase the ability to exploit the results of the CoDEC project - allowing a real-time approach.
56


CoDEC Dissemination
CoDEC
https://www.codec-project.eu/
Connected Data for Effective Collaboration
CoDEC Presentation and Publications
30th International Baltic Road Conference, August 2021, Riga, Latvia.
18th World Meeting of the International Road Federation, Nov 2021, Dubai.
German EU Council, the Federal Ministry of Transport and Digital Infrastructure (BMVI) conference for "Open Data for Smart Mobility in Europe, Jan 2022
TRA 2022 Lisbon (Nov 2022)
OCW mededelingen/Bulletin du CRR published by BRRC
FEHRL Infrastructure Research Meeting – FIRM2021, 2022
Institute of Asset Management, UK, Nov 2021
PIARC Routes/Roads magazine special issue, 2022
57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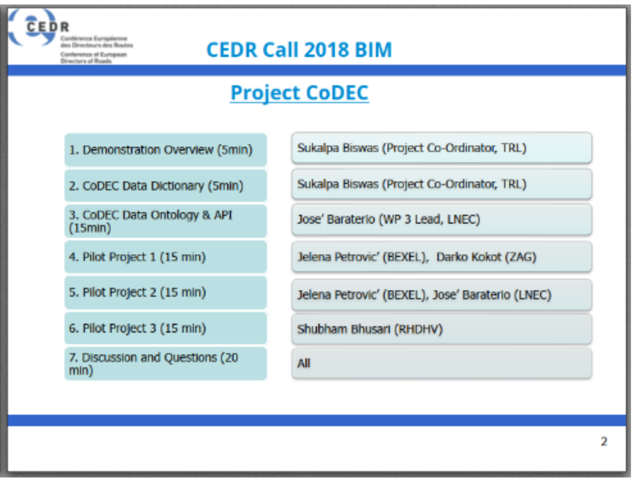
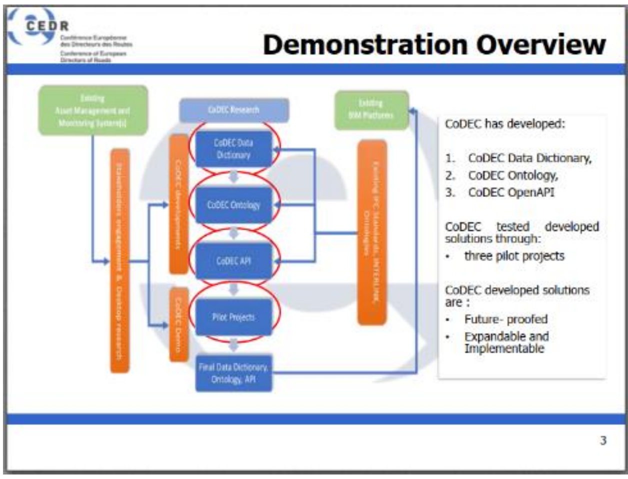
6. Project Recommendations & Disseminations (5 min)
Sukalpa Biswas (Project Co-Ordinator, TRL)
7. Feedback & Questions (20min)
All
58

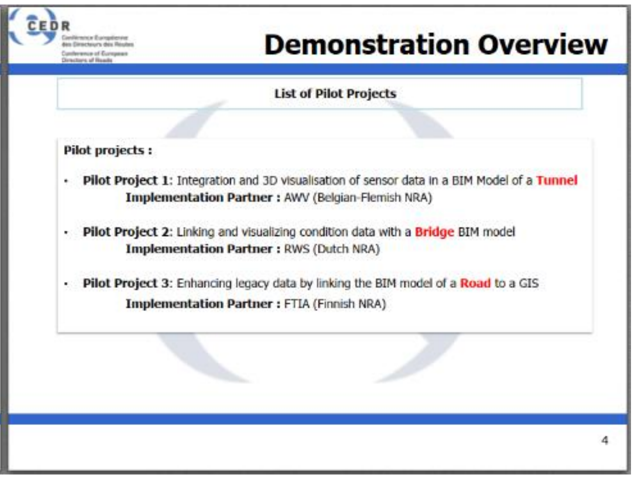

Feedback and Questions
59

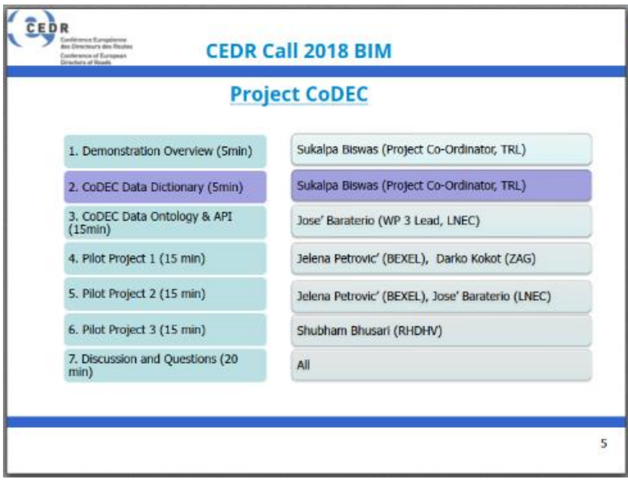

CoDEC
Connected Data for Effective Collaboration
THANK YOU!
60

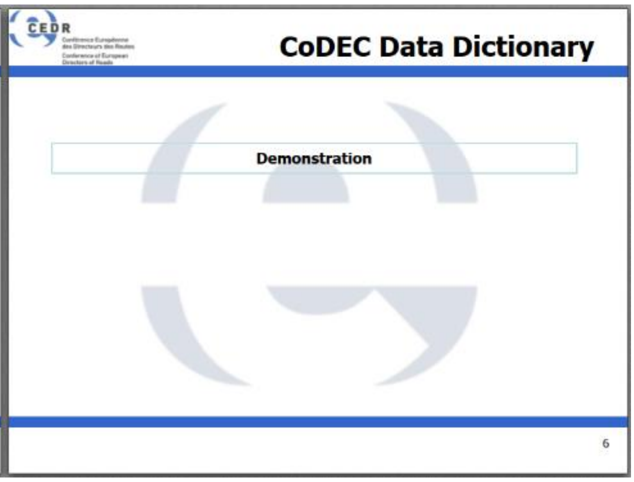
A.4.2 Day 2 presentations

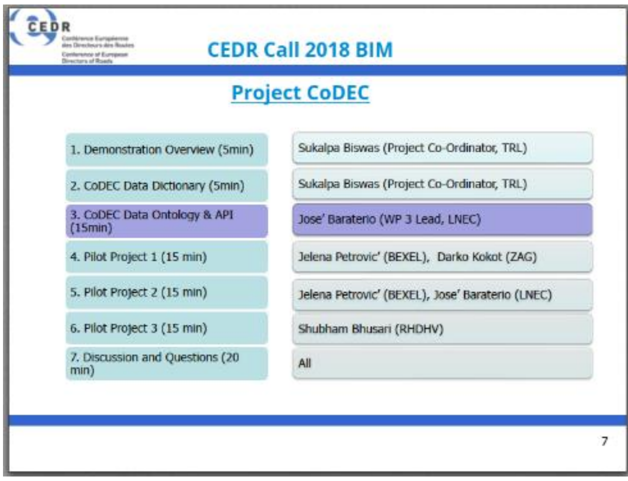


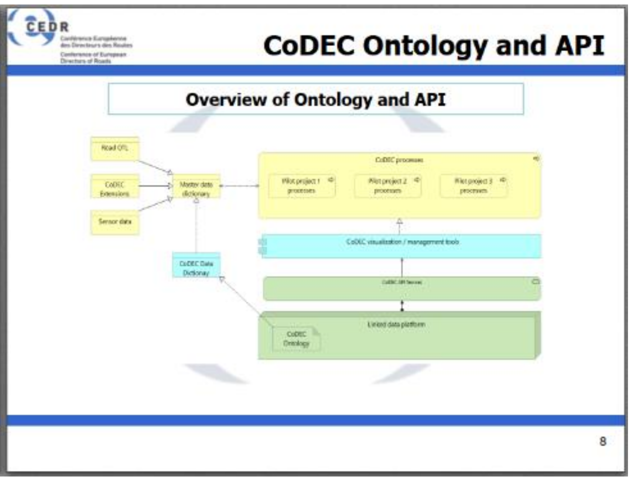


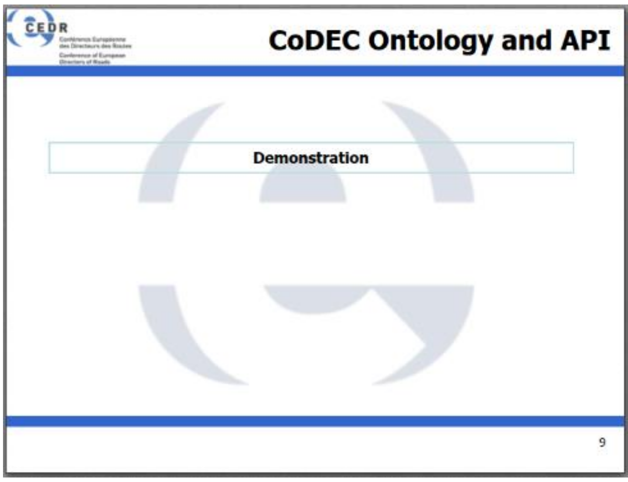


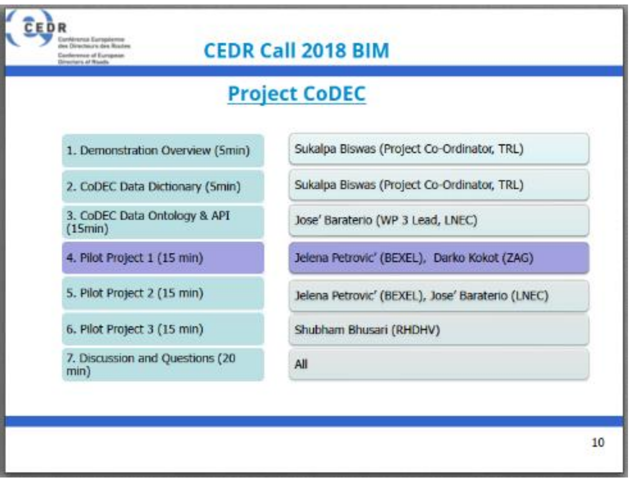





CEDR Call 2018 BIM
Project CoDEC
1. Demonstration Overview (5min)
Sukalpa Biswas (Project Co-Ordinator, TRL)
2. CoDEC Data Dictionary (5min)
Sukalpa Biswas (Project Co-Ordinator, TRL)
3. CoDEC Data Ontology & API (15min)
Jose' Baraterio (WP 3 Lead, LNEC)
4. Pilot Project 1 (15 min)
Jelena Petrovic' (BEXEL), Darko Kokot (ZAG)
5. Pilot Project 2 (15 min)
Jelena Petrovic' (BEXEL), Jose' Baraterio (LNEC)
6. Pilot Project 3 (15 min)
Shubham Bhusari (RHDHV)
7. Discussion and Questions (20 min)
All
7


CoDEC Ontology and API
Overview of Ontology and API
8


CoDEC Ontology and API
Demonstration
9


CEDR Call 2018 BIM
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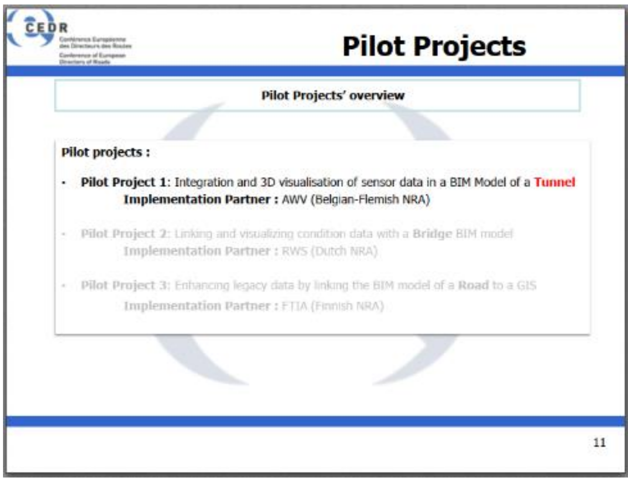
All
10


Pilot Projects
Pilot Projects' overview
Pilot projects :
Pilot Project 1: Integration and 3D visualisation of sensor data in a BIM Model of a Tunnel
Implementation Partner : AWV (Belgian-Flemish NRA)
Pilot Project 2: Linking and visualizing condition data with a Bridge BIM model
Implementation Partner : RWS (Dutch NRA)
Pilot Project 3: Enhancing legacy data by linking the BIM model of a Road to a GIS
Implementation Partner : FTIA (Finnish NRA)
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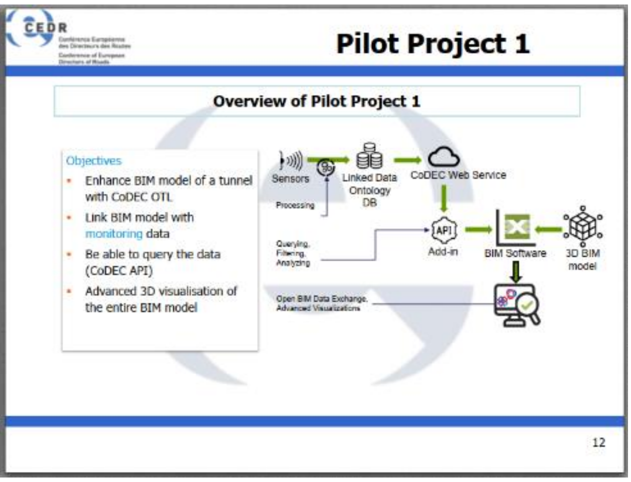
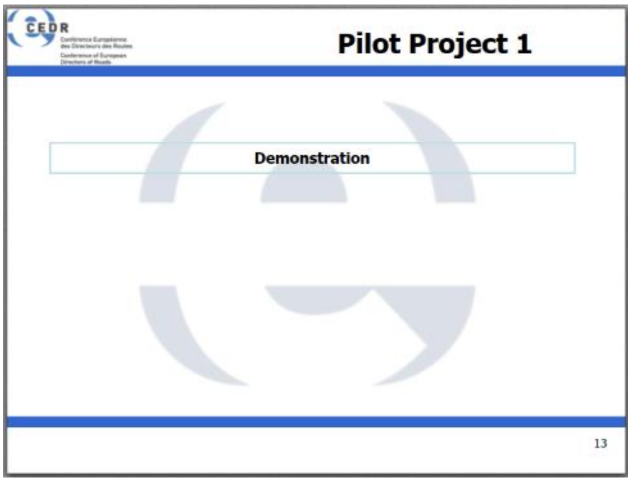

Pilot Project 1
Overview of Pilot Project 1
Objectives
Enhance BIM model of a tunnel with CoDEC OTL
Link BIM model with monitoring data
Be able to query the data (CoDEC API)
Advanced 3D visualisation of the entire BIM model
Sensors
Linked Data Ontology DB
CoDEC Web Service
Processing
Querying, Filtering, Analyzing
Add-in
BIM Software
3D BIM model
Open BIM Data Exchange, Advanced Visualizations
12


Pilot Project 1
Demonstration
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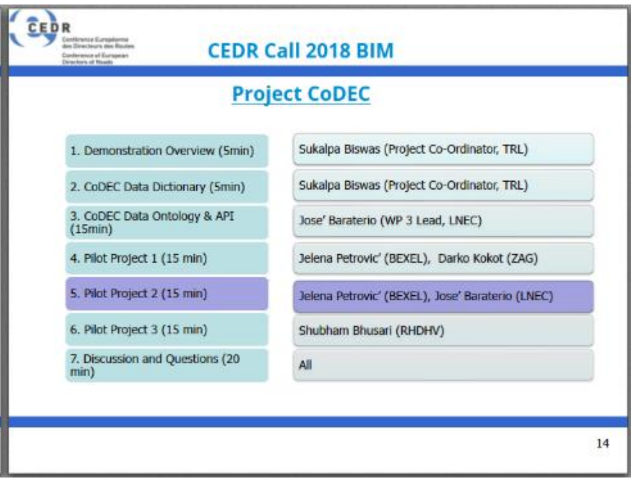
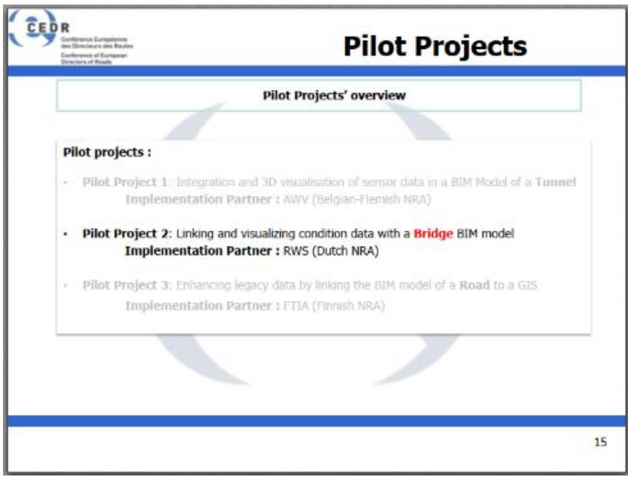

CEDR Call 2018 BIM
Project CoDEC
1. Demonstration Overview (5min)
Sukalpa Biswas (Project Co-Ordinator, TRL)
2. CoDEC Data Dictionary (5min)
Sukalpa Biswas (Project Co-Ordinator, TRL)
3. CoDEC Data Ontology & API (15min)
Jose' Barateiro (WP 3 Lead, LNEC)
4. Pilot Project 1 (15 min)
Jelena Petrovic' (BEXEL), Darko Kokot (ZAG)
5. Pilot Project 2 (15 min)
Jelena Petrovic' (BEXEL), Jose' Barateiro (LNEC)
6. Pilot Project 3 (15 min)
Shubham Bhusari (RHDHV)
7. Discussion and Questions (20 min)
All
14


Pilot Projects
Pilot Projects' overview
Pilot projects :
Pilot Project 1: Integration and 3D visualisation of sensor data in a BIM Model of a Tunnel
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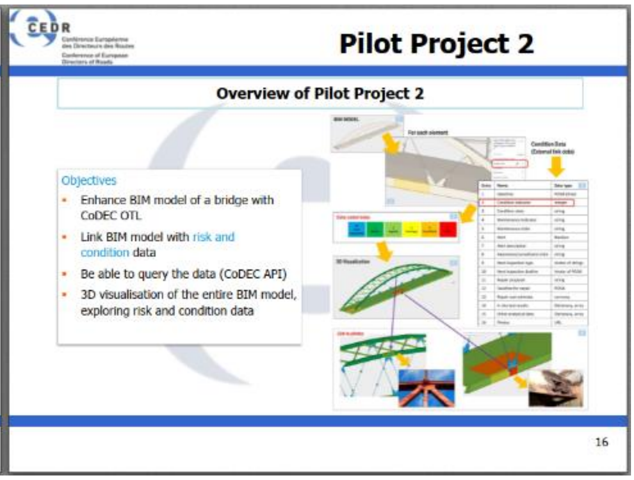
15


Pilot Project 2
Overview of Pilot Project 2
Objectives
Enhance BIM model of a bridge with CoDEC OTL
Link BIM model with risk and condition data
Be able to query the data (CoDEC API)
3D visualisation of the entire BIM model, exploring risk and condition data
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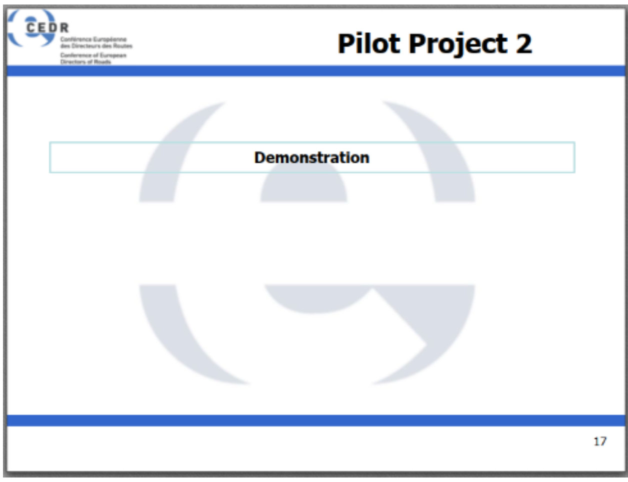
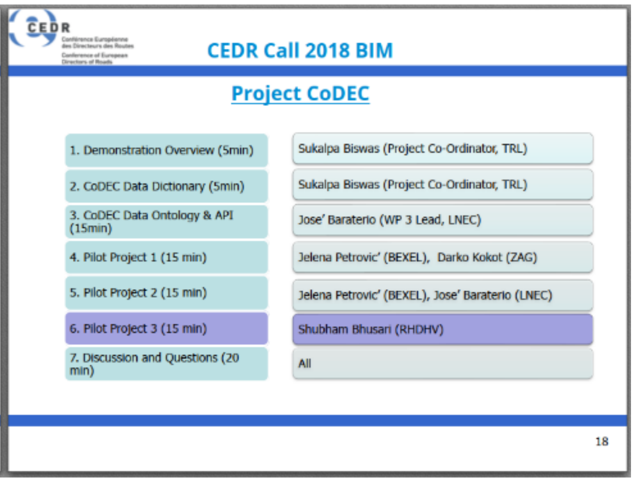

Pilot Project 2
Demonstration
17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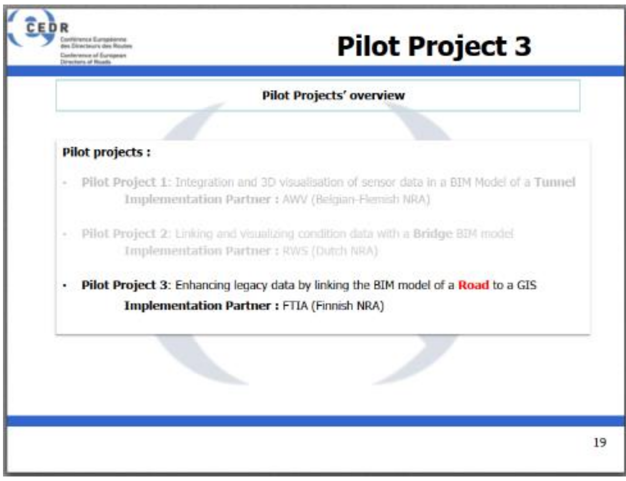
Shubham Bhusari (RHDHV)
7. Discussion and Questions (20 min)
All
18



Pilot Project 3
Pilot Projects' overview
Pilot projects :
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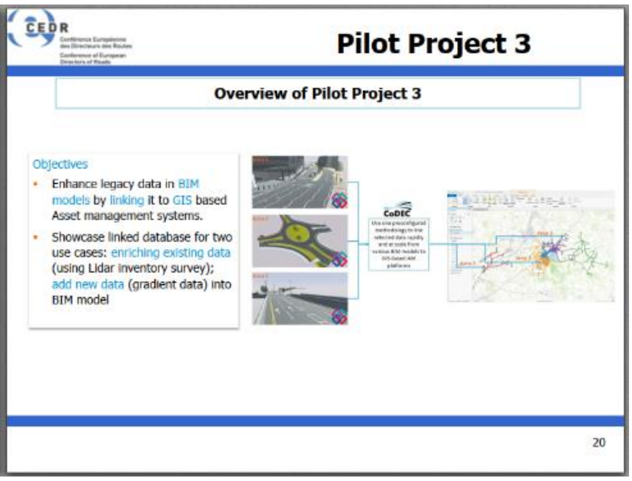
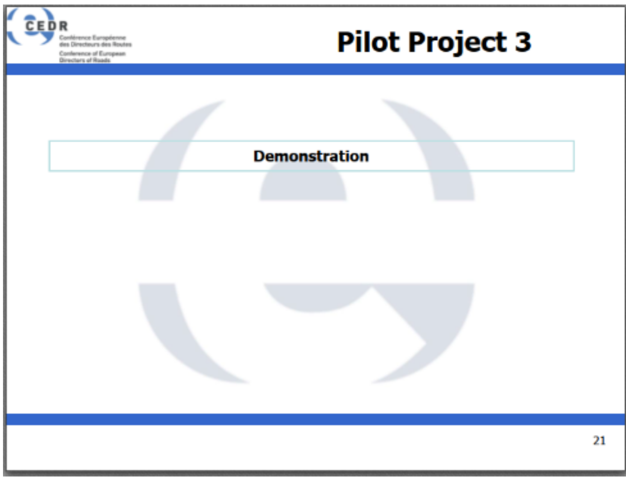
Implementation Partner : AWV (Belgian-Flemish NRA)
Pilot Project 2: Linking and visualizing condition data with a Bridge BIM model
Implementation Partner : RWS (Dutch NRA)
Pilot Project 3: Enhancing legacy data by linking the BIM model of a Road to a GIS
Implementation Partner : FTIA (Finnish NRA)
19



Pilot Project 3
Overview of Pilot Project 3
Objectives
Enhance legacy data in BIM models by linking it to GIS based Asset management systems.
Showcase linked database for two use cases: enriching existing data (using Lidar inventory survey); add new data (gradient data) into BIM model
CoDEC
20



Pilot Project 3
Demonstration
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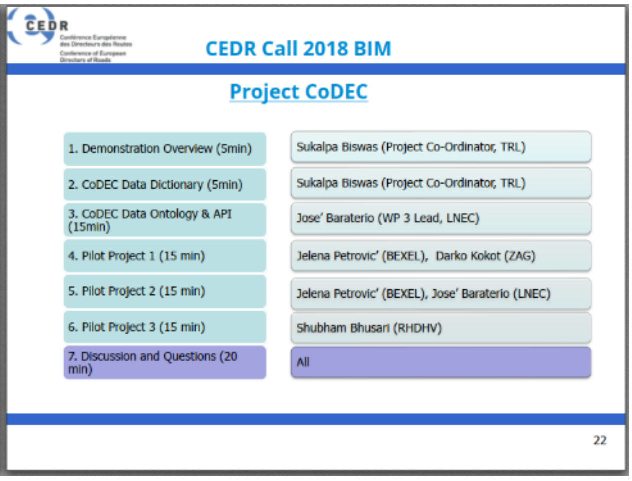

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7. Discussion and Questions (20 min)
All
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CoDEC
Connected Data for Effective Collaboration
THANK YOU!
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CEDR Contractor Report 2022-11

Final Programme Report from CEDR Research Programme Call 2018 BIM

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Conference of European Directors of Roads

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