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Digital Road Operator Information and Data Strategy (DROIDS)

BIM representation for full life cycle of road infrastructure

Deliverable D3.3 Version 1.0

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DRAFT deliverable

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CEDR Call 2022 Data: Maintaining and sharing the digital road infrastructure

Digital Road Operator Information and Data Strategy (DROIDS)

D3.3 BIM representation for full life cycle of road infrastructure

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Executive summary

The concept of a digital twin, a virtual replica of a physical asset, has gained significant traction across various industries. In the context of road infrastructure, the potential of digital twins to optimize asset management, improve decision-making, support Automated Driving Systems (ADS) and enhance operational efficiency is immense. Building Information Modeling (BIM) has emerged as a cornerstone technology in realizing this vision. However, the current utilization of BIM often remains confined to the early stages of the asset lifecycle, such as design and construction. BIM processes during early stages of asset's lifecycle result in a digital model which, combined with data from sensors, can create a digital shadow. This digital shadow can support the creation of a digital twin which is a real time replica with two-way data connection.

This research aims to explore the potential of using BIM digital representations for a comprehensive digital twin that addresses the entire life cycle of road infrastructure, rather than supporting it only in early stages like design and construction. By leveraging BIM data from the initial design stages and transferring it in a structured format to the operational phase like asset management, the aim is to reduce the need for redundant data capture and create a more cohesive and informed digital twin. It also aims to provide a stepwise plan for the recycling and expansion of BIM representations.

Scope

This deliverable presents the results of research carried out during the Task 3.3: Potential of using BIM representations within Work Package 3 of DROIDS. It aims to provide answers to the following DROIDS project Research Questions (RQ):

RQ9: How, and to what degree, can BIM representations be reused for other purposes in the later stages (AIM and ITS) to reduce the need for new data capture for NRAs and Map Providers?

RQ10: How should the [BIM] information be maintained throughout the life cycle of the road infrastructure, given the many different stakeholders involved in the maintenance of the physical infrastructure?

RQ11: Could the NRAs' OTLs (Object Type Libraries) be extended to cover information for the full life cycle?

Methodology

To gather information about the current state of the art around key concepts, a literature review was carried out. This concerns information gathered during the previous phase of the project as well as previous CEDR projects. INTERLINK and CoDEC were used as a starting point to conduct the literature review. On top of that, the BIM standard ISO 19650 was used to understand managing information over the whole life cycle of built assets.

To gather information about the current practices of road operators in relation to BIM and OTL, interviews were conducted with BIM and OTL experts within 4 road operators (Belgium, Denmark, Finland, and Ireland). The interviews focussed on capturing the current use of BIM representations, BIM contents, stakeholders involved, contents of OTL and understanding the process of keeping information up to date.

Current state of BIM Information Maintenance among road operators

Road operators across Europe are increasingly adopting BIM to enhance project delivery, improve collaboration, and optimize asset management. However, the level of BIM maturity varies significantly among different countries. While some road operators, like *Ireland*, are in the early stages of BIM implementation, focusing on developing policies and standards, others, such as *Belgium*, have more advanced practices, utilizing BIM models from the design phase through to construction and aiming to extend their use to asset management.

Despite these advancements, several common challenges hinder the effective maintenance of BIM information. These challenges include the lack of standardized data, difficulties in data sharing and integration, and resistance to change. For example, in *Ireland*, the manual approval process and limited use of a Common Data Environment (CDE) hinder efficient information exchange. In *Denmark*, while BIM models are used, there is a disconnect between different project phases, and the lack of data dictionaries limits data standardization. *Finland* faces challenges in ensuring data quality and utilizing historical data. *Belgium*, while making progress, faces resource limitations and market readiness issues.

State of Object Type Libraries (OTLs) utilisation within road operators

The utilization of OTLs for BIM information management varies significantly among road operators. Some, like *Belgium*, have well-developed and integrated OTL systems. AWV in Belgium boasts a comprehensive OTL that covers the entire asset lifecycle, encompassing data flow, signal flow, and asset locations. They continuously improve their OTL based on user feedback and best practices. Other road operators, like *Ireland*, are in the early stages of OTL development. TII in Ireland is currently creating data dictionaries and OTLs, but policy implementation is still pending. There are also cases where road operators haven't adopted OTLs at all. *Denmark*, for example, currently relies on a project-wise approach with a naming convention for BIM information management. This lack of standardization poses challenges in data integration and future OTL development.

The focus of OTL extension also differs among road operators. *Belgium* is actively expanding its OTL to include more asset types and integrate dynamic information like sensor data. *Finland*, on the other hand, is currently prioritizing information standardization but has plans to explore OTL extension for digital twin creation in the future. This highlights the need for road operators to consider their specific needs and priorities when developing and extending their OTLs.

BIM information reuse within road operators

Road operators are increasingly recognizing the value of reusing BIM information throughout the asset lifecycle. In *Ireland*, the focus is on validating BIM information to ensure alignment with design intent. *Denmark*, on the other hand, relies on layer-based models, which can limit data reuse. *Belgium* has developed a comprehensive approach to BIM information reuse, extracting relevant data from BIM models and integrating it into an asset database. *Finland* emphasizes the importance of standardizing information transfer and centralizing project data to facilitate reuse.

Key challenges in BIM information reuse include integration and system compatibility, standardization, software dependency, and data quality. To address these challenges, road operators should prioritize standardization, training, and the adoption of flexible software solutions. By implementing these strategies, road operators can improve the efficiency and effectiveness of their asset management processes, leading to better-informed decision-making and long-term sustainability.

Proposed process of BIM information reuse

To effectively recycle BIM representations throughout the full lifecycle of digital twins for road infrastructure, road operators can implement the process as outlined in section 7.4:

a. *Define Objectives and Scope:* Clearly define the goals and scope of BIM reuse, considering data availability, requirements, and stakeholders.
b. *Establish Standards and Guidelines*: Develop and adopt BIM standards, ISO 19650, and OTLs to ensure consistency and interoperability.
c. *Establish Collaboration and Communication*: Foster collaboration between BIM and AIM teams, engage stakeholders, and simplify processes.
d. *Identify Information Requirements*: Define and prioritize information requirements aligned with OTL.
e. *Facilitate Data Exchange:* Implement data governance, utilize CDEs, and establish data transfer protocols.
f. *Integrate BIM into Design Processes:* Collect and standardize BIM data, incorporate BIM from early stages, and link BIM models to OTL.
g. *Ensure Data Quality:* Implement quality control procedures, validate data against OTL, and conduct data audits.
h. *Integrate BIM with Asset Management Systems:* Develop data migration strategies and integrate BIM data to enrich asset management systems.
i. *Data Management and Maintenance:* Ensure continuous data updates, quality assurance, and effective change management.
j. *Monitoring and Evaluation:* Conduct regular assessments, establish a feedback loop, and plan for scaling.

By following these steps and prioritizing change management, road operators can successfully reuse BIM information to enhance asset management and digital twin development.

Conclusion

This research explored the practices and challenges surrounding BIM information management within road operators for road infrastructure. The findings highlight the potential of BIM for improved asset management, decision-making, and overall lifecycle optimization. However, challenges such as a lack of standardization, data quality issues, and limited interoperability hinder effective BIM information reuse.

To address these challenges, the research recommends a stepwise approach for road operators. This approach emphasizes the standardization of data through the use of ISO 19650 and OTLs. It also highlights the importance of collaboration, training, and the adoption of flexible software solutions. By implementing these recommendations, road operators can unlock the full potential of BIM information reuse, leading to a more efficient and effective approach to road infrastructure management.

Furthermore, the research identified key considerations for extending road operator's OTLs to cover the entire lifecycle of assets. This includes incorporating feedback from stakeholders, expanding the OTL to encompass a wider range of assets and data types, and ensuring standardization and interoperability through the adoption of open standards. Finally, the research proposes a process for effectively recycling BIM representations throughout the full lifecycle of digital twins for road infrastructure. This process emphasizes collaboration, data quality control, and integration with asset management systems. By following these recommendations, road operators can create a more sustainable future for their road networks through the effective use of BIM and digital twins.

DROIDS project description

DROIDS is a CEDR Transnational Road Research Programme Call 2022 project aiming to provide the road operators, including European National Road Authorities (NRAs), increased knowledge and support to reap optimal benefits from digitalisation as they evolve to become digital road operators operating the physical, operational and digital road infrastructures. As digital road operators, the road operators will provide better road user services while improving road transport's safety, efficiency and sustainability.

The background of the research is the ongoing transformation of the road operators to digital road operators responsible for operating both the physical and digital road infrastructure. Some road operators have already developed their processes and services accordingly, while some are still reflecting on the developments and discussing the transformation.

First the project will look at the evolving roles of the road operators as they transform themselves into digital road operators. Special focus is given to new roles brought by digital road operation while changes foreseen about the existing roles are addressed. DROIDS pays specific attention to the role evolution in different CEDR member countries with currently varying roles and digital maturity.

Secondly, the project studies the evolution of digital twins from road data banks to comprehensive real-time digital twins of the road transport system, including the infrastructures, traffic, land use, road environment etc. Here, the integration of the digital twins with the processes in the road operator's core business and tasks is assessed in a thorough manner.

Thirdly, trust has been identified as the key attribute for road operator originated data/information concerning its use by private sector stakeholders such as vehicle manufacturers and service providers. Thereby DROIDS also highlights the issues related to ensuring trust and security in the maintenance, sharing, and use of the digital road infrastructure.

Finally, the work of DROIDS concludes in the production of an overarching data strategy for the physical and digital road operators taking on board the results from DROIDS and other ongoing projects (such as the CEDR Data Call 2022 PRESORT and TIARA projects).

Expected achievements and benefits to road operators:

- DROIDS offers road operators a clearer understanding of the prerequisites and roles associated with becoming a digital road operator, vital for road operators considering this transition.
- It emphasizes the crucial step for road operators: adapting processes to maximize benefits from digital tools.
- While DROIDS provides insights for process adaptation, the actual implementation must align with each road operator’s unique digital and organizational maturity.
- The project results will outline specific recommendations regarding actions and roles tied to HD maps, electronic traffic, and transport regulations, aiding road operators in decision-making.

Glossary

AG	Advisory Group
ADS	Automated Driving Systems
AIM	Asset information modelling
AIR	Asset information requirements
AWV	Agentschap Wegen en Verkeer (Belgium)
BIM	Building Information Modelling
bSDD	buildingSMART Data Dictionary
CAD	Computer-aided design
CDE	Common data environment
CEDR	Conference of European Directors of Roads
COBie	Construction Operations Building Information Exchange
CoDEC	Connected Data for Effective Collaboration project funded by CEDR
DROIDS	Digital Road Operator Information and Data Strategy project funded by CEDR
DT	Digital Twin
DTF	Digital Transformation Framework
EC	European Commission
EU	European Union
FTIA	Finnish transport infrastructure agency
GPS	Global Positioning System
IFC	Industry Foundation Classes
INTERLINK	INformation managemenT for European Roads using LINKed data project funded by CEDR
ISO	International Organization for Standardisation
ITS	Intelligent Transport Systems
IoT	Internet of Things
KPI	Key performance indicator
LAN	Local area network
LOD	Level of Detail
n.d.	No date mentioned in the reference
NBIMS	National Building Information Modelling Standard

NRA	National Road Authority. NRA is often used in Europe. This study uses a term “road operator” that also includes NRAs.
OKSTRA	Objekt katalog für das Straßen- und Verkehrswesen - Object Catalog for Road and Traffic Networks
OSLO	Open Standards for Linking Organisations
OTL	Object Type Library
PIM	Project information model
PLC	Programmable logic controller
PRESORT	ImPRoving thE uSe Of third-paRTy data by NRAs project funded by CEDR.
RWS	Rijkswaterstaat, the Netherlands
TIARA	
TII	Transport Infrastructure Ireland
UML	Unified modeling language
WAN	Wide area network

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1 Introduction

The concept of a digital twin, a virtual replica of a physical asset, has gained significant traction across various industries. In the context of road infrastructure, the potential of digital twins to optimize asset management, improve decision-making, support Automated Driving Systems (ADS) and enhance operational efficiency is immense. Building Information Modeling (BIM) has emerged as a cornerstone technology in realizing this vision. However, the current utilization of BIM often remains confined to the early stages of the asset lifecycle, such as design and construction.

This research aims to explore the potential of using BIM representations for a comprehensive digital twin that addresses the entire life cycle of road infrastructure. By leveraging BIM data from the initial design stages and transferring it in a structured format to the operational phase like asset management, the aim is to reduce the need for redundant data capture and create a more cohesive and informed digital twin.

There has been a lot of efforts towards standardisation of BIM information in recent years. Various road operators are standardising their information requirements with the help of Building Smart Data Dictionaries (bSDD)[1]. The release of Industry Foundation Class (IFC) 4.3 in April 2024[2], also expanded the domain within IFC from just buildings to road, railways, tunnel, geotechnical, bridges, alignments and port & waterways, allowing greater standardisation and digital representation of information within the transportation domain. These advancements bring opportunities for more BIM information to be reused and recycled from the design and construction phase into the maintenance and operation phase.

The focus of this research is on identifying the elements within BIM representations that can be recycled for purposes beyond design and construction, particularly in the areas of Asset Information Management (AIM) and Intelligent Transport Systems (ITS). Additionally, we investigated the feasibility of extending existing Object Type Libraries (OTLs) to encompass information required for the full asset lifecycle.

Through a combination of literature research and in-depth interviews with BIM experts from various road authorities, this report aims to develop a stepwise plan for recycling and expanding BIM representations. The goal is to harness the power of BIM to create a more efficient, sustainable, and resilient road infrastructure.

Chapter 2 explains the purpose and scope of this deliverable. Chapter 3 introduces the methodology of the study and project as well as the research methods used. Chapter 4 aims to shed light into the state of the art and defines various key concepts. Chapter 5 discusses the current practices within road operators in BIM information management and maintenance. Chapter 6 highlights the developments around OTL within road operators and discusses OTL extension possibilities. Chapter 7 focuses on BIM information reuse for later stages within the assets' lifecycle. Chapter 8 finally concludes the findings.

[1] https://www.buildingsmart.org/users/services/buildingsmart-data-dictionary/
[2] https://www.buildingsmart.org/the-status-of-ifc-4-3-and-the-benefit-of-further-extensions-as-ifc-4-4/

2 Purpose and scope

The DROIDS project aims to provide the road operators, including European National Road Authorities (NRAs), increased knowledge and support to reap optimal benefits from digitalisation as they evolve to become digital road operators operating the physical, operational and digital road infrastructures.

This deliverable presents the results of research carried out during the Task 3.3: Potential of using BIM representations within Work Package 3 of DROIDS. In this task the focus lies on the potential of using BIM representations for a digital twin addressing the full life cycle of the road infrastructure, rather than supporting it in only early stages like design and construction. It also aims to provide a stepwise plan for the recycling and expansion of BIM representations.

It provides an answer to the research questions as in Table 1 below. The main research questions are also broken down in sub-research questions.

Table 1: DROIDS project Task 3.2 research questions and related research questions which of the latter are addressed in this deliverable.

DROIDS Task 3.3 research question	Sub-Research Questions	Deliverable Chapter
(RQ10) How should the [BIM] information be maintained throughout the life cycle of the road infrastructure, given the many different stakeholders involved in the maintenance of the physical infrastructure?	What are the current practices in relevance to the management of BIM information within NRAs?	5.1 & 5.2
	Who are the key stakeholders involved in the maintenance of the road infrastructure and what are their information needs?	5.3
(RQ11) Could the NRAs’ OTLs (Object Type Libraries) be extended to cover information for the full life cycle?	How do current NRAs' Object Type Libraries (OTLs) structure and store information relevant to road infrastructure?	6.1
	How can NRAs' OTLs be extended or modified to accommodate information relevant to the entire lifecycle?	6.2 & 6.3
(RQ 9) How, and to what degree, can BIM representations be reused for other purposes in the later stages (AIM and ITS) to reduce the need for new data capture for NRAs and Map Providers?	What are the current practices regarding the reuse of BIM information within NRAs?	7.1
	Which specific elements within BIM representations can be identified and recycled for use in Asset Information Modeling (AIM) and Digital Twin (DT)?	7.2
	What processes can be developed to effectively recycle BIM representations throughout the full lifecycle of digital twins for road infrastructure?	7.4

The **Scope of this research** is extracted from the expected results of DROIDS Work Package 3 “Digital Twin application evolution” as presented in the Table 2 below.

Table 2: DROIDS project Work Package3's expected end results and the scope of this deliverable.

DROIDS WP3 expected end results	Deliverables
ER1.1 - Building on results of WP2, The state of the art. (technical and functional aspects)	D2.1 & D3.1 (combined report)
ER1.3 - How the information should be maintained and made available for maintenance contractors, map producers and road users throughout the lifecycle of the road infrastructure. (technical and functional aspects)	This deliverable (D3.3)
ER1.4 - Considerations regarding standards and standardisation processes and the expected level of complexity for the data.	D3.2
ER1.5 - Requirements for digital representation of traffic rules and regulations, including the need for a physical representation of restrictions in the future and the potential for improved utilization through more dynamic regulations.	D3.4
ER4 - Report describing proof of concepts: A possible flow of information from BIM to HD Maps for new road sections to prepare the digital infrastructure for automated transport in parallel with the opening of the physical infrastructure	D3.4
ER5 - Report describing proof of concepts: Provision of authoritative information needed for automated lane-level navigation to ensure automated vehicles navigate legally through complex traffic environments	D3.4

This deliverable's results provide the basis for the next phases and work packages knowledge creation in the DROIDS project, i.e., input for further research and analysis.

Key terminology

1. It is to be noted that **the term "road operator"** is used in this deliverable to describe any public or private entity that is responsible for the planning, maintenance and management of the road, including management of traffic flows. The term "road operator" therefore also covers road authorities that are public authorities responsible for similar tasks. The term has been here adapted from the European Commission delegated regulation (EU) 2022/670 of real-time traffic information services (EC 2022). The term National Road Authority (NRA) is often used in Europe to describe a Member State national authority that is responsible for the previously mentioned tasks; in this study, the term road operator is also used to cover NRAs.

2. While the concept of Digital Twin has numerous definitions, the **DROIDS definition of Digital Twin** was formulated which is as follows:

   "**Road transport Digital Twin** is a virtual representation of the real-world physical road transport systems. The road transport Digital Twin includes digital representation of elements such as road infrastructure, traffic with vehicles and pedestrians, road environment and land use. The road transport Digital Twin has a bidirectional real-time data connection between the physical and the digital representation. It can support road operator decision making with dynamic monitoring, analysis, and predictive modelling capabilities of the road transport systems that enable road operators for instance to enhance traffic flow, road safety and infrastructure asset management or to facilitate automated driving.”

The DROIDS definition of Digital Twin will be iteratively reviewed throughout the project based on input and feedback from the project stakeholders. Therefore, the above-mentioned DT definition can be changed in later (DROIDS) deliverable reports. The final definition will be published in the final report (Data Strategy).

3 Methodology

The study's initial research questions and expected results were derived from the CEDR funding call of Data Call 2022, which were then formalised in the DROIDS project proposal's project plan. The scope of the study was limited in the CEDR Call and DROIDS project proposal to a qualitative assessment of digital twin state-of-the-art. The research questions were iteratively reviewed together with the project team as the research work progressed. During the research question reviews it was evaluated what background information and knowledge would be required from the study that would later benefit the next deliverables and stages of the project, and therefore, the final results of the project, i.e., the National Road Authorities Data strategy.

The DROIDS project has also been working with digital twin taxonomy, the first development cycle of which was synchronized with this deliverable. The aim of the taxonomy development was to ensure the use of common definitions of key concepts and terms, such as digital twin, and language throughout the project. The taxonomy was reviewed by external partners of CEDR road authorities and the DROIDS Advisory Group. The latter included public authorities, universities, research centres and private industry members such as service providers.

Project Methodology

The DROIDS project utilises the Digital Transformation Framework (DTF) structured approach that supports the design, development, planning and management of necessary organisational transitions. The DTF adopted for the DROIDS project is illustrated in Figure 1. Within the DTF, it is important to ensure vertical and horizontal alignment between the different columns and layers.

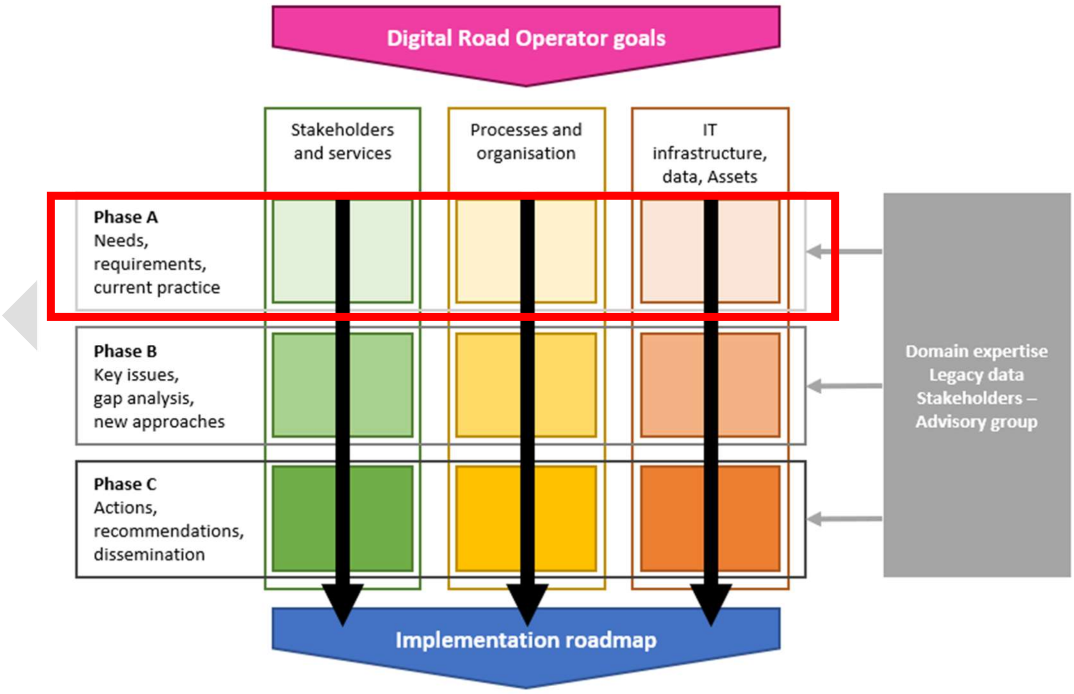

Figure 1 DROIDS project's Framework

Vertical Alignment: This refers to the strategic alignment between requirements, gaps, and actions to fill these gaps, which form the three phases of the project. It follows a top-to-bottom approach, translating overall goals into relevant business cases and roadmaps. The information gained in one layer supports the content creation in the layer below, ensuring a consistent way of achieving the business cases, overarching strategy, and implementation roadmap.

Horizontal Alignment: This ensures completeness by not focusing only on technology or stakeholders but also considering other important organizational factors. It ensures alignment between stakeholders, core business, internal processes, and IT for an organization. This alignment produces the expected outputs holistically and is taken into account in the individual work packages. It pays special attention to alignment with key stakeholders.

This deliverable is a part of the first horizontal DTF Phase A that determines needs, requirements, and current practices as highlighted by a red box in the Figure 1.

Research Methodology

In order to gather the required information to achieve the objectives, a literature review was carried out. The results from existing and prior work conducted in CEDR projects (CoDEC and INTERLINK) were considered in desktop research as a starting point to enable the work carried out now and in the future work of the DROIDS Work Packages. The close liaison with CEDR projects PRESORT and TIARA was very useful in ensuring the state-of-the-art information acquired in those. Furthermore, 4 interviews were conducted with BIM experts within road operators to understand the current state of BIM representations within their organisations and their developments in Object Type Library (OTL) contents.

Literature review methodology

The information gathered during the previous phase of the project as well as previous CEDR projects: INTERLINK and CoDEC was used as a starting point to conduct the literature review. On top of that, BIM standard ISO 19650 was used to understand managing information over the whole life cycle of built asset. The research was then conducted around the main and sub research questions to gather relevant information. Furthermore, from the identified resources, snowballing was carried out to identify more relevant literature. In addition, any information shared by the stakeholders via questionnaire or during interaction such as AG meetings, consortium meetings, collaboration meetings etc. was also used.

Interview methodology

To gather information about the current practices of road operators in relation to BIM and OTL, interviews were conducted with BIM and OTL experts within the road operators. The interviews focussed on capturing the current use of BIM representations, BIM contents, stakeholders involved, contents of OTL and understanding process of keeping information up to date. The questions asked in the interview can be found in Appendix A.

A total of 4 organisations were interviewed. Table 3**Error! Reference source not found.** provides an overview of various organisations who were interviewed.

Table 3: An overview of organisations who were interviewed

Organisation	Country	Interview date
Danish Road Directorate (Vejdirektoratet)	Denmark	14 Aug 2024
Finnish Transport Infrastructure Agency (Väylävirasto)	Finland	19 Aug 2024
Transport Infrastructure Ireland (TII)	Ireland	26 Aug 2024
Agentschap Wegen & Verkeer (AWV)	Belgium	28 Aug 2024

4 State of the Art

This chapter aims to provide state of the art around various key terminologies and definitions that are discussed within the scope of task 3.3 of DROIDS.

4.1 Building information Modelling (BIM)

BIM is an acronym for Building Information Modeling. According to ISO 19650, “BIM is the use of a shared digital representation of a built asset to facilitate design, construction and operation processes to form a reliable basis for decisions” (ISO 19650-1, 2018). U.S. National BIM standard (NBIMS) defines BIM as “a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle; defined as existing from earliest conception to demolition.”

BIM is the process of creating and managing information for a built asset throughout its entire lifecycle. It is a collaborative process which allows engineers, contractors, manufacturers, architects, asset owners and other stakeholders to plan, design, construct, maintain and operate the infrastructure. BIM facilitates the creation and sharing of information throughout the design, construction and operation phase of an asset (What Is BIM | Autodesk, n.d.; What Is BIM (Building Information Modeling), Trimble, 2022).

4.1.1 Digital representations as part of BIM

BIM is fundamentally rooted in the creation and management of digital representations. These representations, often referred to as models, serve as the basis of the BIM process, providing a comprehensive digital information of a physical asset. One of the key elements within the BIM workflow is creating and managing such digital representation or model of the asset.

BIM uses a digital model to represent the physical and functional characteristics of the infrastructure, from its design and construction to its operation and maintenance. The most common type of digital representation are geometric models which provides detailed 2D or 3D representation of the infrastructure. This provides information about the size, shape, and spatial relationships of various components. However, BIM models are not just visual representations but also contain rich information about the infrastructural elements such as material, maintenance, costs, performance etc. Furthermore, these models can also be linked with external data sources (such as traffic information) and can be used for advanced simulation to optimise the infrastructure’s performance or safety (Castañeda et al., 2021). Figure 3 and Figure 4 provides a few examples of BIM digital representations.

The digital models can also be enriched with more information (or dimensions) such as time/scheduling (4D), quantity/cost (5D), energy efficiency and sustainability (6D) and maintenance and management (7D) (“BIM Dimensions - 2D to 7D,” n.d.). Creating a digital model of the asset in BIM enables those who interact with the asset to optimize their actions, resulting in a greater whole life value for the asset.

Figure 2: An example of BIM digital representation from ROAD-BIM (ROAD-BIM, 2018)

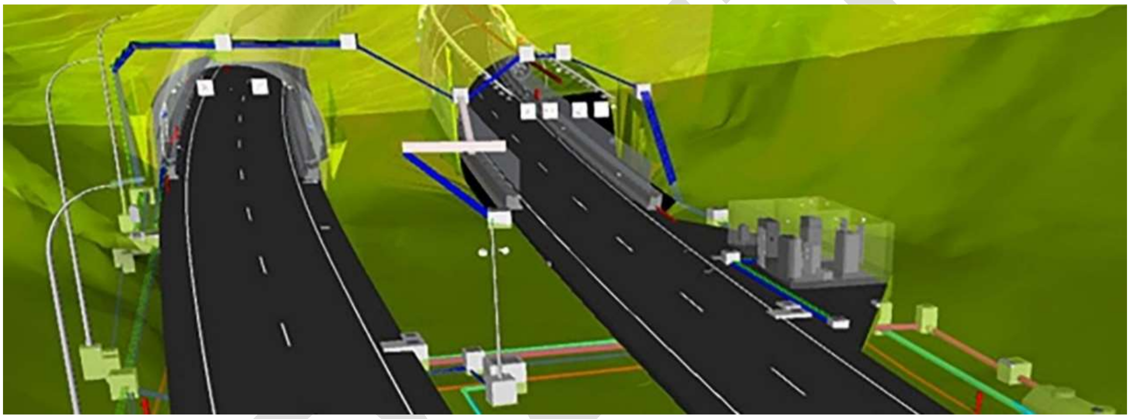

*Figure 3: BIM model from a tunnel renovation project in N-644 Spain (*Dair Engineering*, 2019)*

Several key components of BIM digital models are (Sharon, 2024):

- **Objects and Elements:** In BIM models, infrastructural elements are represented as objects and elements, such as pavement, cables, gantries, structural components etc. These objects have both geometric and data attributes.
- **3D Modelling:** BIM models are developed in three dimensions, which provide a comprehensive view of the infrastructure's design and allows for clash detection and spatial analysis.
- **Data Integration:** BIM integrates various types of data, including geometric data, attributes, time schedules, cost estimates, and more. This data can be accessed and modified by various stakeholders.
- **Parametric Design:** BIM models can also use parametric modelling, allowing changes to one element to automatically update related elements. This leads to increased design flexibility and accuracy.
- **Collaboration and Information Sharing:** BIM models facilitate collaboration among all project stakeholders by providing a centralized platform for information sharing and real-time updates.

4.1.2 BIM standards

BIM is widely used in construction, but its benefits extend to the operation and maintenance of industrial assets. There are multiple BIM standards that exists today ranging from regional standards such as BS 1192 series (UK) and NBIMS (National Building Information Modeling Standard) (US) to international standard ISO 19650 series as one the first international BIM standard series to be introduced.

The ISO 19650 series includes five published documents, covering various aspects of information management throughout the asset lifecycle, from project delivery (ISO 19650-2) to asset operation (ISO 19650-3), information exchange (ISO 19650-4), and information security (ISO 19650-5). A sixth document, addressing health and safety (ISO 19650-6), is under development. The standards are linked to other ISO guidelines like ISO 55000 for asset management and ISO 9001 for organizational management, ensuring comprehensive information flow throughout a project's lifecycle. The ISO 19650 series contains five parts as follows (ORINOX, 2023):

Part 1: Concepts and Principles ISO 19650-1

The first part of the ISO 19650 standard provides an overview of the concepts and principles of BIM for industrial assets. It defines BIM as a digital representation of physical and functional characteristics of an asset, which can be used for decision-making throughout the asset lifecycle. The standard emphasizes the importance of a collaborative approach to BIM, with clear communication, roles and responsibilities, and information exchange protocols. It also highlights the need for data quality and security, as well as the use of common data environments (CDE) to manage and share BIM data.

Part 2: Delivery Phase of the Assets ISO 19650-2

The second part of the ISO 19650 standard focuses on the delivery phase of the assets, which includes the design, construction, and commissioning of the asset. It outlines the requirements for BIM deliverables, such as models, drawings, and specifications, as well as the information exchange protocols between the parties involved in the project. The standard also sets out the requirements for the management of BIM data, including the use of a CDE, the definition of data requirements, and the verification of data quality.

Part 3: Operational Phase of the Assets ISO 19650-3

The third part of the ISO 19650 standard covers the operational phase of the assets, which includes the maintenance, renovation, and decommissioning of the asset. It highlights the importance of a seamless transition from the delivery phase to the operational phase, with the transfer of BIM data and documentation. The standard sets out the requirements for the management of BIM data during the operational phase, including the use of a CDE, the definition of data requirements, and the verification of data quality. It also emphasizes the use of BIM for asset management, such as the monitoring of performance, maintenance scheduling, and risk assessment.

Part 4: Collaborative Production of Information ISO 19650-4

The fourth part of the ISO 19650 standard focuses on the collaborative production of information, which is the core of BIM. It outlines the requirements for information management, such as the identification of information requirements, the definition of information exchanges, and the validation of information quality. The standard also sets out the requirements for the management of BIM data, including the use of a CDE, the definition of data requirements, and the verification of data quality. It emphasizes the importance of a structured approach to information management, with clear roles and responsibilities, communication protocols, and change management procedures.

Part 5: Asset Information Requirements ISO 19650-5

The fifth and final part of the ISO 19650 standard sets out the requirements for asset information requirements (AIR), which are the information needs for an asset throughout its lifecycle. It defines the process for identifying, validating, and documenting AIR, as well as the requirements for the delivery of AIR in the form of BIM data and documentation. The standard also emphasizes the importance of a collaborative approach to AIR, with clear communication, roles and responsibilities, and information exchange protocols.

4.1.3 BIM maturity levels

The origin of ISO 19650 can be found in two British standards: BS 1192 and PAS 1192-1. Bew and Richards (2008) developed the UK BIM maturity model. The UK Code for BIM defines the BIM maturity levels from level 0 (no collaboration) to level 3 (full collaboration). Figure 4 showcases the wedge diagram of BIM technology maturity levels as defined by Bew and Richards (2008).

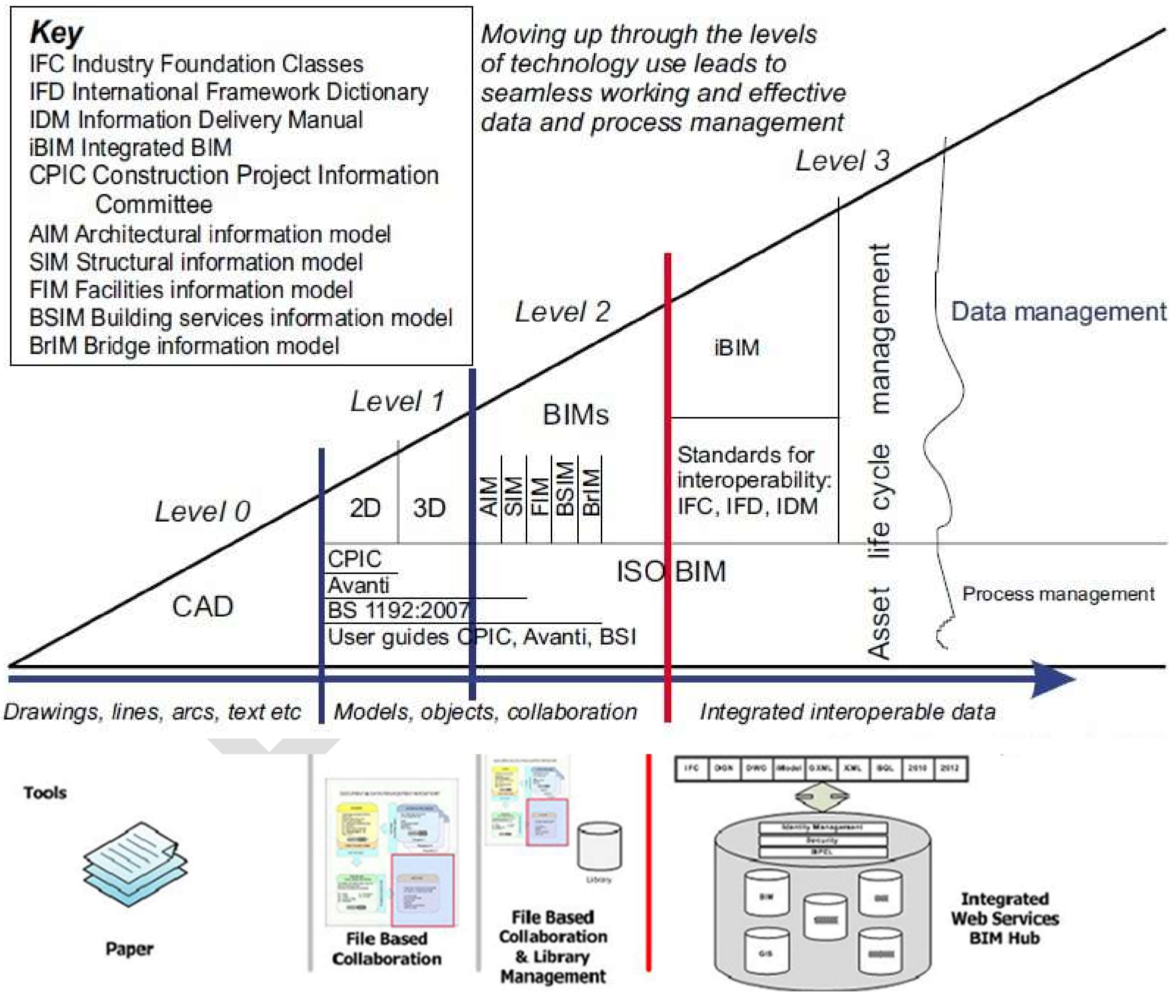

Figure 4: BIM Technology Maturity Levels (Bew & Richards, 2008)

The various levels of BIM maturity are defined as follows (Fernando Morales Tosar, 2022)

- **Level 0:** This is the primary level which includes 2D CAD (Computer Aided Design) for drafting and its output is simply distributed along the stakeholders via paper or electronic prints. At this stage, there is no combination of any BIM enabling software.

- **Level 1:** This is a combination of 3D CAD models and 2D drafting documents with information about the product. This represents the current level for most organizations that are involved in the construction The collaboration is increased within the internal departments of the organization itself and 3D CAD models are more common. The attachment of data representing different sides of the project with lower model and 2D drawings are mostly used for documentation of work and production of shop drawings.

- **Level 2:** This is a level which operated by collaborative practices. Each participant in this level is working on their own 3D model. It comprises the sharing of data through common file formats like Industry Foundation Classes (IFC) and Construction Operations Building Information Exchange (COBie). Therefore, each party is entitled to use any type of BIM software on the condition that it is interoperable with the formats agreed upon for information exchange purpose.

- **Level 3:** This level uses a full collaborative process with a single shared model. It represents the future of collaboration among different construction stakeholders and throughout all the construction processes. This allows all stakeholders to access the updated information. Paperless project based on the 'cloud-based' data will be extended to the execution of the project where rugged tabs replace the conventional shop drawings. This allows the risks to be reduced by reducing the conflict of information.

4.1.4 Common Data Environment (CDE)

CDE refers to a digital platform which is used to centralise storage and access of project data by various stakeholders. The data stored in CDE originally consists of BIM data and information as per workflow recommended by ISO 19650 series. ISO 19650-1 (2018) defines CDE as "agreed source of information for any given project or asset, for collecting, managing and disseminating each information container through a managed process."

The information stored in CDE also includes documents like project contracts, estimates, reports, material specifications, and other information relevant to a project's design and construction processes (Trimble construction, 2022). Multi-disciplinary project stakeholders can access the information from CDE at anytime and anywhere using a computer, mobile phone, tablet, or machines in the field. CDE make it easier for everyone involved in the project to access and share up-to-date project information. This helps streamline the project and ensures everyone is working with the same data.

ISO 19650 defines requirements for a CDE which include (1) using a unique identifier for every "information container" and a standard naming convention, (2) assigning a "suitability status" to all data, (3) controlling data revisions to ensure past revisions aren't actively being used, (4) implementing an audit trail, and more.

4.1.5 openBIM and openCDE

openBIM and openCDE are initiatives in development by buildingSMART international to bring open standards to BIM and CDE.

openBIM is a collaborative approach to building information modeling that ensures data is accessible, usable, and sustainable. It promotes vendor-neutral processes and facilitates seamless collaboration among project participants, improving project efficiency and asset lifecycle management. (*openBIM Definition - buildingSMART International*, 2020). Industry Foundation Classes (IFC) is an example of openBIM standard for digital description of the built asset industry. (*Industry Foundation Classes (IFC) - buildingSMART International*, 2019)

openCDE is a family of standards for providing connectivity and open communication between Common Data Environment platforms and BIM tools for the building and infrastructure sectors in the construction resources industry (https://github.com/buildingSMART/OpenCDE-API).

4.2 Asset information model (AIM)

An AIM is a model that compiles the data and information necessary to support asset management, that is, it provides all the data and information related to, or required for the operation of an asset (*Asset Information Model AIM*, 2022)

AIM extends BIM principles beyond the construction phase into the entire lifecycle of an asset. By creating a detailed digital representation of the physical and functional characteristics of an asset, comprehensive information can be accessed throughout a project's lifecycle. These models include data about design, construction, operation, and maintenance. AIM production typically integrates into the later stages of the BIM workflow, specifically during the operational and maintenance phases when the digital model transitions into a dynamic tool for ongoing asset management. AIM is defined as information model relating to the operational phase in ISO 19650-1 (2018).

The AIM comprises models, data, documents and other records related to or required for the operational phase of an asset. It might include information outlining the original design intent, details of ownership, survey work undertaken, operational performance details as well as 3D models developed on the project (*Richard McPartland, 2017).*

An AIM can provide graphical and non-graphical data and information as well as documents and metadata. It can relate to a single asset or to a portfolio of assets. An AIM can be created from existing asset information systems, from new information, or from information in a Project Information Model (PIM) that was created for the construction of a new asset. When AIM is built using the data from PIM, it is done using **Pull-principle**, i.e., only the required information is fetched from PIM.

4.3 From BIM to AIM to Digital Twin (DT)

It was explored in section 4.1 that BIM establishes process for enabling standardised data formats, structured information management and framework for governance and information. In addition, the models resulting from the BIM process are digital representation of as built infrastructure. Since digital twins aims to integrate various types of good quality data such as static data resulting from BIM process and dynamic data in a single platform, BIM could provide a foundation for the development of digital twin.

Heatton and Parlikad (2020) proposed a BIM-based approach for designing and developing DTs. Their approach leverages the object-oriented nature of BIM models to create an AIM, which serves as the foundation for the Digital Twin.

Their study presented a case study from the West Cambridge campus to illustrate the development of a single 3D model. This model integrates multiple BIM models with rich metadata attached based on a pre-defined asset classification schema. The key aspect of this approach is aligning the development of an AIM to facilitate DT creation.

The proposed approach consists of three key steps, as depicted in below Figure 5:

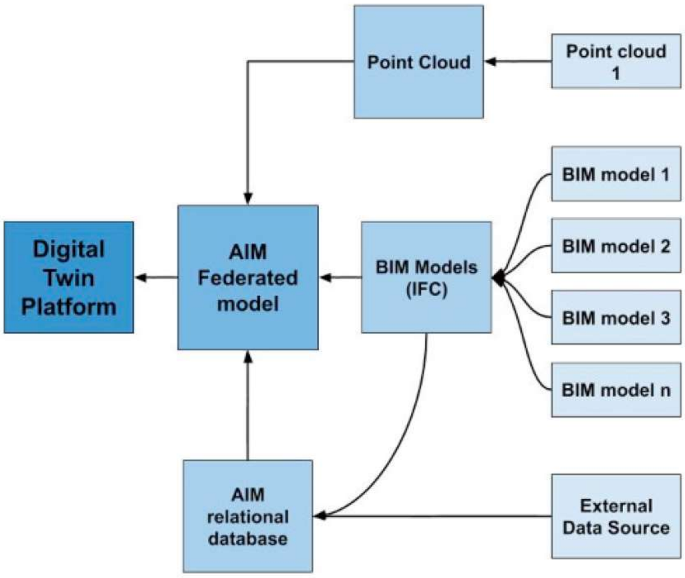

Figure 5 overview of the approach (Heatton and Parlikad, 2020)

Step 1: Structuring a BIM model into AIM

This step involves structuring BIM information (maybe from PIM model) for transition into AIM model. The assets within the BIM digital representation are categorised based on their functions. For asset classification, OTL can play a significant role in managing information. First an appropriate asset classification system is adopted and then classification is attached to the assets in BIM model (since BIM models are object-oriented). If the OTL was adopted during the BIM process, it helps with asset classification.

The asset classification is then further documented as unified modeling language (UML) diagrams which can be adopted further in BIM implementation for similar projects as shown in Figure 6.

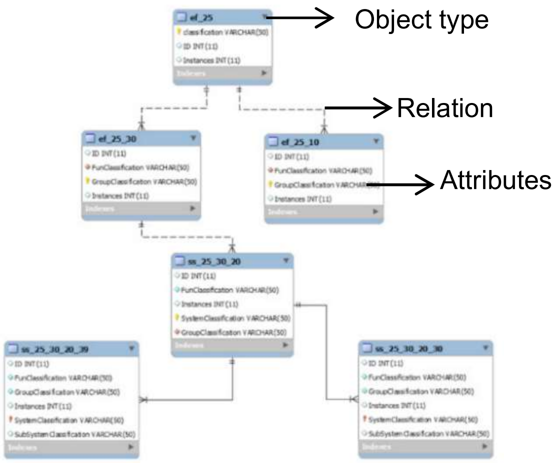

Figure 6: Example of Asset classification UML diagram (Heatton and Parlikad, 2020)

Step 2: AIM database development

Using the structured and enriched BIM information along with asset classification, AIM database is developed which reflects a system of assets in real works and their relationships. Such relational database creates a connection between different assets in AIM and BIM models. Additionally, it establishes a set a list of required attributes for new assets in database from other sources.

Step 3: Federated Asset Information Model

The third step is to develop an AIM federated model which combines information from various sources such as AIM relational database, point cloud data or geometry data. All the important information from BIM model, AIM relational database and other information from different sources is available through federated AIM.

The federated asset information model then can be utilised in creating a digital twin of road infrastructure.

Many authors have explored the potential of using BIM models for Digital Twins. Porsani et al. (2021) highlighted that BIM is a foundational step towards Industry 4.0, which encompasses virtual reality and Digital Twins as key components. Gurevich and Sacks (2020) suggested that integrating as-designed and as-built BIM models into Digital Twin information systems could enhance organizational operations. According to Rausch et al. (2021), the construction industry relies on as-built data and 3D geometry from BIM to create Digital Twins. Antonino et al. (2019) demonstrated that Digital Twins could be developed by integrating real-time information with BIM. Furthermore, White et al. (2021) and Zhu and Wu (2021) proposed that Digital Twin smart cities could be created by combining BIM with large datasets from IoT and GIS, respectively.

4.4 Data dictionary

ISO 23386:2020 defines a data dictionary as a centralized repository of information about data such as meaning, relationships to other data, origin, usage and format. It is a structured list of descriptive information about data in plain language (easily readable by humans). Three main purposes have been mentioned for Data Dictionary: it provides the data structure to build Object Type Library (OTL), It makes the object types understandable for asset managers, and finally it helps to expand the incorporation of other data types for an asset in the future.

4.5 Object type library (OTL)

An OTL is a standardized information model that defines and organizes object types in a structured manner. These object types can represent various infrastructural elements such as bridges, roads, tunnels, streetlights etc. and contains information about their characteristics such as maintenance date, contractor, location etc. The object types in the information model are structured in such a way that the object types have a certain relationship with each other that can be expressed in different ways. For example, an object type traffic signal might have a relation with an intersection on road. (*Object Type Library - Platform Linked Data Nederland*, n.d.)

An OTL acts as a common language, ensuring everyone involved understands the meaning and relationships between information. Just like dictionaries for natural languages, an Object Type Library provides a common framework for improving communication between different parties and their software systems (Rikkert, 2023, 2024, *OTL Publicatieomgeving*, n.d.). An OTL contains various objects (or elements of asset) which contain information about their classes, list of attributes and relationship with other objects in OTL.

OTLs offer several benefits. They can be used as dictionaries to prevent misunderstandings and misinterpretations in data exchange, both by humans and software. They can also improve data gathering and transformation by explicitly linking relevant data points. Additionally, OTLs based on open standards improves interoperability and enable seamless data exchange between different businesses and applications. (Rikkert, 2024)

The specific use of an OTL depends on its purpose and different organization may have different OTL. OTLs are mainly used in BIM models to ensure correct, uniform, usable and consistent data across the lifecycle of an asset. OTLs define the information that should be linked to each BIM object, creating a uniform foundation for all BIM models.

The starting point of the OTL are objects in the real world. For example, a roadside camera installation includes a light pole, a cabinet, a bridge, a tunnel, a traffic sign, the vertical road structure, but also less visible and yet essential parts for the correct operation of physical parts such as software components. The OTL describes these objects and records relevant properties (including option lists) and relationships. (*BIM and Asset Lifecycle Management for Road Infrastructure | Autodesk University*, 2022). Figure 7 showcases an example extracted from AWV-OTL showcasing the object types, attributes and relationship between different object types.

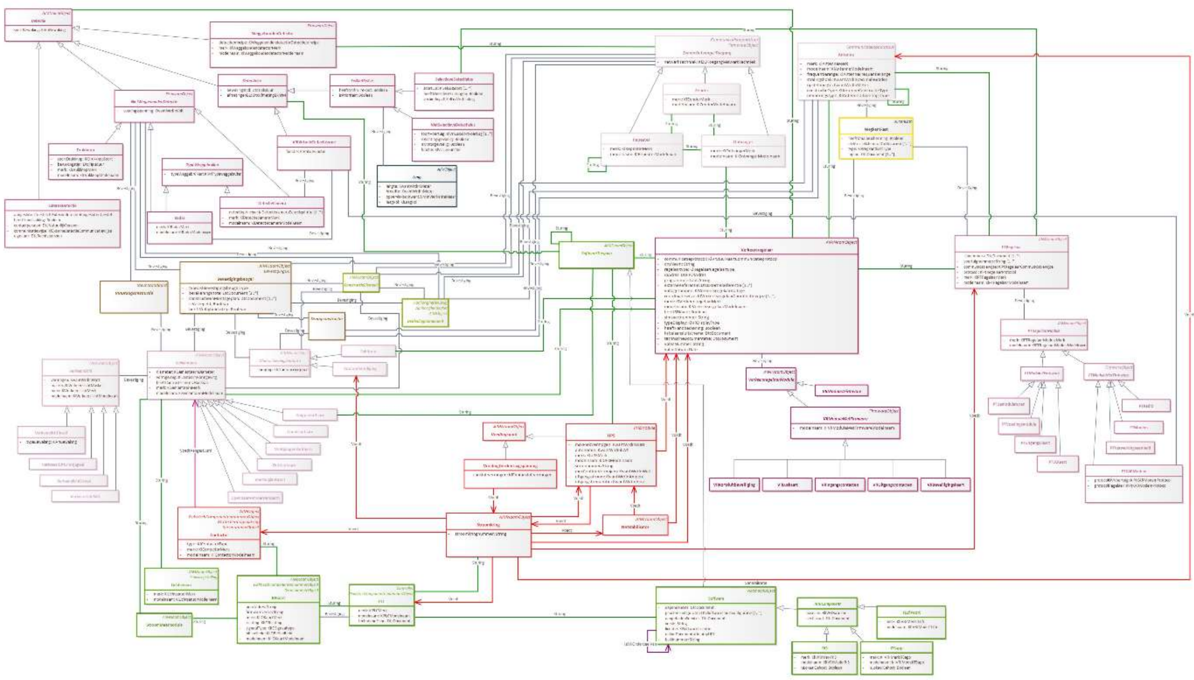

*Figure 7: An example from AWV-OTL showcasing the object types, their attributes and relationships of Traffic control system (*Verkeersregelinstallatie*, 2024)*

An OTL is a machine-readable representation of data dictionary. It provides a more structured and explicit way to define relationships between datasets, using mechanisms like hyperlinks and unique references based on a defined ontology. While it can reference a data dictionary as its base, it's not mandatory. OTLs are often designed to have relationships with each other and can be linked to data dictionaries using predefined object types. (CoDEC deliverable D1a, 2020)

While there's no single universal OTL, different OTLs can be mapped to each other for better interoperability. The Netherlands has a standard for OTLs called NEN 2660-1:2022 (previously NEN NTA 8035), which provides rules for information modelling of the built environment (*Jan*

Voskuil, 2021).

In conclusion, OTLs are valuable tools for standardizing data exchange and communication. They act as a common language, improving data quality, facilitating data reuse, and enabling seamless information sharing across different domains.

4.5.1 Difference between OTL and data dictionary

While both OTL and data dictionaries are used for defining and organizing information, OTLs are more focused on objects and their relationships, are explicitly machine-readable, and often adhere to standards for interoperability. Data dictionaries, on the other hand, can have a broader scope and may not be as structured or machine-readable. Table 4 highlights a few key differences between OTL and data dictionary.

Table 4: Differences between OTL and Data dictionary

Feature	OTL	Data Dictionary
Purpose	Defines object types, their properties, and relationships	Defines terms, their meanings, and usage
Structure	Hierarchical or graph-based	Often tabular
Scope	Focuses on objects and their attributes	Covers a broader range of terms and concepts
Machine Readability	Explicitly designed for machine interpretation	May not be machine-readable
Relationships	Clearly defines relationships between objects	May not explicitly define relationships
Interoperability	Aims for seamless data exchange	May not prioritize interoperability
Standardization	Often based on standards (e.g., NEN NTA 8035)	May or may not be standardized

4.5.2 Examples of OTL implementation

Several road authorities have published their object type libraries to enable different stakeholders easily access the relevant information. This ensure clear definitions, relationships, and agreements about the various infrastructure objects enabling clarity and consistency in data and processes.

The Netherlands – Rijkswaterstaat (RWS)

https://otl.rws.nl/ (in Dutch)

Rijkswaterstaat (RWS), Dutch ministry of infrastructure in the Netherlands has a clear, comprehensive, and well defined OTL for Rijkswaterstaat's entire area of responsibility, which includes a vast network of infrastructure, such as roads, dams, bridges, and waterways. Their OTL currently contains object types, their properties and relationships from 4 standards: NEN-2660, NEN-2767, SATO and UTD. Among these standards, NEN-2767 contains most comprehensive objects and their attributes for road transport systems. Figure 8 shows screenshot of RWS-OTL website showcasing the object classes, types, their attributes and relationships.

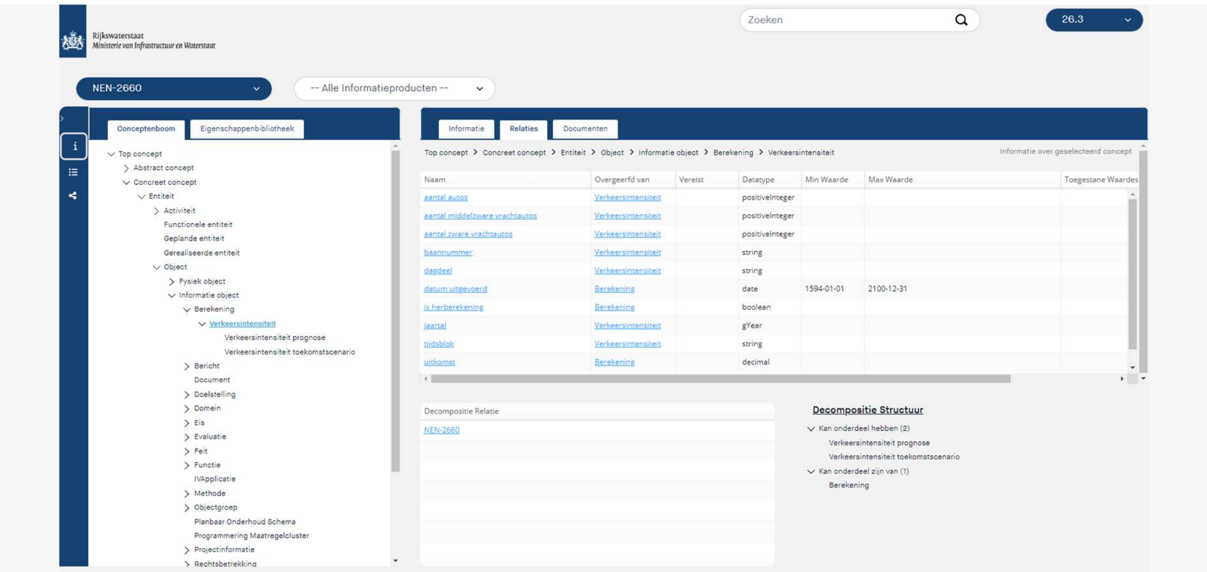

Figure 8: Screenshot of RWS-OTL webpage highlighting classes, object types, and various attributes

An example of a few objects relevant to the digital representation of road transport systems in RWS-OTL are given in Table 5.

Table 5: Example of a few object type categories in Rijkswaterstaat's OTL

Category	**Object type / components**
Traffic control systems	Loop detectors, wiring, warning lights, actuators (push button), gantries, traffic signals, processing unit etc.
Road surface	Foundation layer, intermediate layer, top layer, asphalt reinforcement, undercoat, elevation etc.
Roadside systems	Servers, processing unit, display, mast, wiring, control panel, detector, cupboard etc.
Traffic detection installation	Camera, loop detector, processing unit, wiring etc.
Local control installation	Local area network (LAN), Field bus, Wide area network (WAN), server, switch, emergency stop, control panel, programmable logic controller (PLC)
Slippery road warning system	Camera, Infrared lamp, sensor, wind gauge, server, mast, wiring etc.
Dynamic signage and information systems	Display, switch, server, processing unit, solar panel, beam lighting etc.

Belgium (Flanders) - Agentschap Wegen en Verkeer (AWV)

https://wegenenverkeer.data.vlaanderen.be/ (in Dutch)

The AWV OTL specifies an implementation model for the data exchange during the entire life cycle of components and installations that are broadly related to roads and traffic as specified in the various Standard Specifications 250, 260 and 270. These standards can be found at https://wegenenverkeer.be/zakelijk/documenten. Development of OTL within AWV is a part of Open Standards for Linking Organisations (OSLO) programme, where the Flemish government is committed to a clear standard for the exchange of information.

The AWV-OTL allows for more precise and standardized specifications to be created for construction partners. The AWV anticipates BIM processes to incorporate OTL-structured data. This ensures that BIM from various partners is consistent and compatible. The end goal is to establish a digital replica of the entire road network, enabling more effective management and maintenance (GEONIIUS, 2017).

The various objects within the OTL are categorized in sub-categories such as camera installation, dynamic boards, IP Network, Signalling, Speed and red-light cameras, access control, tunnel evacuation, Traffic control system etc. In addition, a separate section of the website also provides definitions of various terms used.

Germany – Federal Ministry of Transport and Digital Infrastructure (BMDV)

https://www.okstra.de/ (in German)

OKSTRA (Objekt katalog für das Straßen- und Verkehrswesen - Object Catalog for Road and Traffic Networks) was introduced as a nationwide standard by the Federal Ministry of Transport, Building and Urban Development in 2000 (*BASt -OKSTRA®*, 2024). The OKSTRA standard is an object-oriented data model for representing road and traffic data. It was introduced as a means for harmonizing data exchange processes between software systems used for designing, constructing and operating roads. It has become a mandatory standard for exchanging road design data between roadway planners and the road authorities.

It relies on the GML standard and provides capabilities for describing the shape of a road in compliance with established engineering approaches, i.e. by combining the horizontal and vertical alignment with a number of cross-sections. Apart from that it provides a rich set of semantics covering various aspects ranging from road design and condition rating to traffic and incident statistics. OKSTRA is characterized by a very fine granularity and a high degree of detail. (Beetz & Borrmann, 2018)

4.5.3 buildingSMART Data Dictionary (bSDD)[3]

There are a large number of national data models in practical use, while new international data models are on the horizon, but not yet widely implemented. bSDD aims to bring together definitions from different data dictionaries such as IFC, Uniclass 2015, FTIA Road, Digital twin consortium etc. within one database. (*buildingSMART Data Dictionary - buildingSMART International*, 2024)

bSDD is a collection of interconnected data dictionaries with definitions of terms to describe the built environment. The service is provided by buildingSMART for free, to enable easy access from software solutions. The bSDD is an online service hosting classes (terms) and properties, allowed values, units, translations, relations between those and more.

Each data dictionary in bSDD contains definitions of classes and properties to describe the built environment. On top of that, bSDD can store relations between definitions, mapping between classifications, translations, and more. bSDD is designed to improve BIM data quality and consistency, reduce misunderstandings, and enable more effective collaboration in the construction industry.

[3] https://www.buildingsmart.org/users/services/buildingsmart-data-dictionary/

4.6 *Life cycle of built asset*

As described previously in DROIDS deliverable 2.1 and 3.1, whilst BIM refers to the process that encompasses the entire lifecycle of the project, there are several other information models that exist in different phases of the project lifecycle. Figure 9 showcases the BIM information workflow through the design, construction, and operation phases of the project (Catenda 2024). During the design and construction phase, development of Project Information Model (PIM) takes place whereas after the construction, the knowledge and information is transferred to the Asset Information Model (AIM) for the operation and maintenance of the assets.

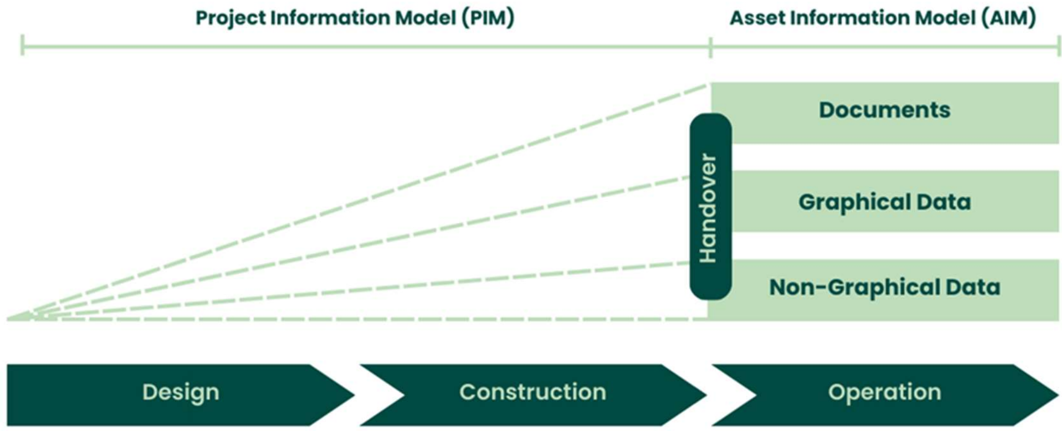

Figure 9: BIM information workflow from PIM to AIM (Catenda 2024)

PIM is the information model developed during the design and construction phase of a project (BSI 2013). PIM includes the federated building information model, non-graphical data, and associated documentation. The PIM Is developed progressively, first as a design intent model and then as a virtual construction model. The design intent model is then developed into a virtual construction model containing all the objects to be manufactured, installed, or constructed.

As the design progresses, the PIM develops, and the level of detail increases. Ultimately, once the construction is complete, the PIM eventually becomes an as-built model to represent the real as-constructed condition of the built asset. After that, the PIM transfers to the AIM to continue informing asset management (AM)/facility management (FM) during the operational phase. Figure 10 showcases the project and asset information management lifecycle as described in ISO 19650-1 (2018).

Key

A start of delivery phase — transfer of relevant information from AIM to PIM

B progressive development of the design intent model into the virtual construction model

C end of delivery phase — transfer of relevant information from PIM to AIM

Figure 10: Generic project and asset information management life cycle (ISO 19650-1)

AIM and PIM are centralized databases containing structured (like geometric models, schedules, and databases) and unstructured information (like documentation, videos, and audio recordings) about built assets. This information is used throughout the asset's lifecycle, from design and construction to operation and maintenance. As the asset ages and changes, the amount of information stored in these models and their uses will likely grow as shown in Figure 11 (ISO 19650-1, 2018).

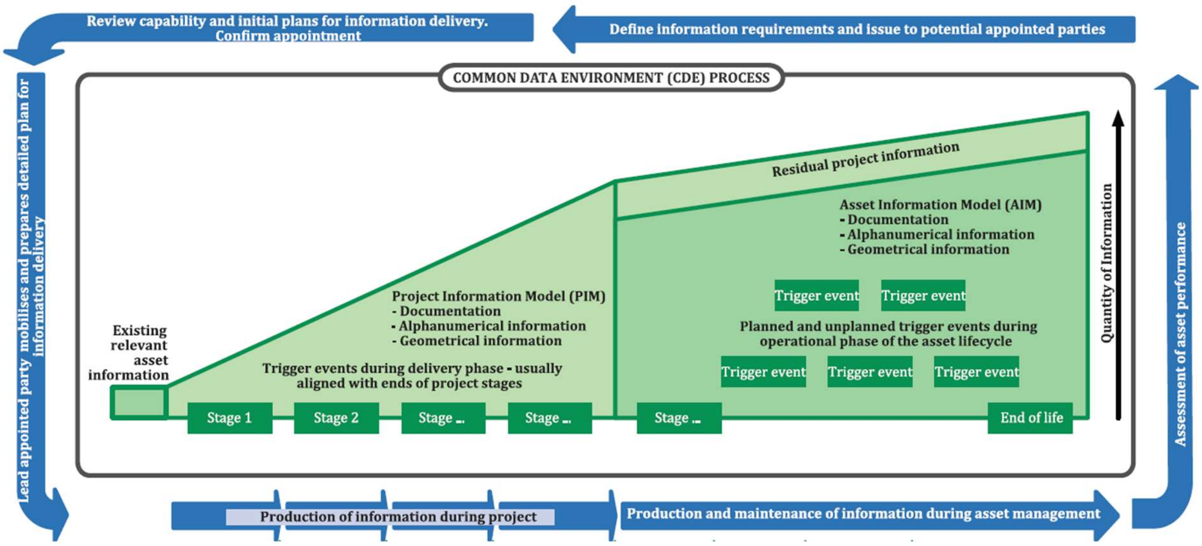

Figure 11: An illustration of information management over asset‘s lifecycle (ISO 19650-1: 2018)

5 BIM information maintenance

Management and maintenance of BIM information is one of the key aspects of BIM information reuse. Over the design and construction phase, a tremendous amount of data can be generated which need to be organised well in to be able to reuse the information at later stage of the assets' lifecycle. This section aims to provide an overview of current practices of road operators (as understood from the interviews) in terms of BIM information maintenance starting from design and construction phase, highlighting their key stakeholders and challenges they face in terms of BIM information maintenance.

5.1 Current practices within road operators

Road operators across Europe are increasingly adopting BIM to enhance project delivery, improve collaboration, and optimize asset management. While the level of implementation varies between countries, there are several common practices emerging among road operators.

Despite the awareness and initial application of BIM among many road operators, the CoDEC Deliverable D1a report (2020) indicates that few have advanced to fully integrating BIM activities throughout their organizations. Most road operators were still in the early stages of BIM maturity, with only a few reaching a level where BIM activities are developed, embedded, and becoming effective. That evaluation also points out that road operators rely on a mix of traditional and modern data collection methods, including visual inspections, machine surveys, and remote sensor data. However, the lack of a unified method for data standardization and the separation of asset management divisions continued to hinder the development of a full lifecycle BIM system. This underscored the need for consistent efforts in standardizing data and integrating BIM across all phases of asset management to realize its full potential.

The various details about current practices of BIM information management within interviewed road operators within DROIDS project is as follows:

5.1.1 Ireland

Transport Infrastructure Ireland (TII) is currently in the early stages of implementing Building Information Modeling (BIM) within its design and construction projects. The organization is operating at approximately Level 2 of the UK BIM maturity model. Efforts are ongoing to develop policies and standards for BIM implementation, with the adoption of ISO 19650 standards on large-scale projects and plans to expand this to all projects.

Design and Construction Phase

During the design and construction phases, TII follows industry standards to create design intent plans and relevant documents. Upon completion of these phases, the information is handed over to the asset management department. However, the asset management department often needs to conduct additional surveys to validate that the BIM models accurately represent the as-built infrastructure. This department uses separate systems and software to store and organize maintenance-related data, which can be analysed to estimate maintenance requirements and update asset information easily.

Data Standardization and Integration

TII is developing data dictionaries and OTL to standardize asset data, enriching them with more attributes based on information requirements. These data dictionaries are intended to be used from the design phase to facilitate easy integration with the asset information model

(AIM). However, as of August 2024, the policy implementation for these data dictionaries is still pending. The current standards for BIM and AIM, which are 10-15 years old, are being updated to align with the new information requirements for AIM. The existing data dictionaries are in the form of Excel spreadsheets listing various objects and associated attributes, but they are not based on open-source standards like Uniclass.

Communication and Data Management

Currently, most communications for approval and data transfer within TII are conducted via email, with files saved in SharePoint and links shared through emails. This manual process is prone to errors and inefficiencies, making it difficult to track links and responses. Additionally, data or products received are saved in separate folders due to security requirements, which restricts access for lower levels of the organizational hierarchy and complicates the checking or updating process.

TII's hierarchical communication structure further lengthens the data transition process, as it is not network-based. This structure means that those at the top of the organizational hierarchy do not engage in day-to-day interactions with other departments to ensure deliverables are completed properly and on time, highlighting the need for a better management system.

Data Formats and Common Data Environment

BIM information within TII is primarily stored and shared in the form of CAD drawings. Recognizing the need for efficient information management, TII acknowledges the requirement for a CDE. Currently, a CDE is organized only for large-scale projects, but there is a recognized need for a company-wide CDE for all projects to streamline information management processes.

Challenges

1. **Data Sharing**: Due to the unavailability of a CDE for many projects, data sharing among stakeholders is challenging. Information is currently shared via emails, making it difficult to find relevant information and leading to significant time investment in locating up-to-date information.
2. **Manual Approval Process**: The approval process is manual and conducted through email exchanges, resulting in scattered information and time wastage.
3. **Tool Selection**: TII is exploring appropriate tools for efficient information exchange within budget constraints.
4. **System Transition**: Convincing management about the benefits of transitioning to a new system is challenging, as there is a common perception among employees that BIM is not necessary for projects.
5. **Compatibility and Interoperability**: Stakeholders use different versions of software, leading to challenges in compatibility and interoperability of datasets.

5.1.2 Denmark

In Denmark, the implementation and management of BIM projects typically involve 2D and 3D object-based models, which represent an initial level of BIM maturity. These models are primarily created using Bentley software. According to Danish directives, designers are required to deliver either 2D or 3D models.

Design and Construction Phase

During the design phase, it is mandatory for companies to deliver 3D and 2D models of project objects. Consultancy firms involved in the construction phase build their work based on these models. This ensures a consistent approach to BIM across different stages of the project.

Leveraging BIM for Asset Information Models (AIM) and Digital Twins (DT)

While 3D and 2D models are archived for the asset management phase, they are often insufficient on their own. For the asset management phase, a dedicated team uses an asset management system compliant with ISO 55000. This team archives design drawings and documents into the AIM.

The initial BIM models used during the design and construction phases are not directly utilized as starting points for the asset management model. Instead, the models are often layer-based CAD drawings, which, although 3D, follow specific standards for layering and object placement. These layers can be exported/imported into the GIS system, but they do not fully meet the requirements of a comprehensive BIM or AIM model.

To enhance the accuracy and detail of the AIM, the team employs Point Cloud to BIM or 3D scanning to BIM techniques. This process involves scanning existing structures with 3D laser devices and converting the scanned data into detailed 3D BIM models, similar to the method used by Google for street view imagery. These models provide a comprehensive virtual representation and as-built information of the infrastructure.

There is a notable disconnect between the models used in different project phases. For example, 2D CAD drawings are converted to 3D models in AIM, losing their connection with BIM models. The final version of the model used in the design and construction phases is updated in the asset information model but remains unconnected to earlier phases.

Challenges and Current Limitations

1. **Use of IFC Models**: Currently, the organization works with CAD objects in layers. However, there is a preference for using more IFC (Industry Foundation Classes) model objects to improve integration and usability.
2. **Validation Process**: Before utilizing information from Project Information Models (PIM), a validation process is necessary to ensure their accuracy and completeness.
3. **Lack of Data Dictionaries**: Denmark does not yet use data dictionaries or object type libraries. Instead, the level of detail (LOD) for objects is defined based on the project requirements.

5.1.3 Finland

In Finland, the use of BIM is primarily focused on large projects, with Finnish Transport Infrastructure Agency (FTIA), also known in Finnish language as Väylävirasto, employing BIM models from the preliminary design phase through to construction. The level of detail in these models varies depending on the project and its specific phases. Finland is also concentrating on extending BIM usage beyond construction, aiming to improve the transfer of information from PIM to AIM through a standard known as Infra Model.

Information Transfer and Standardization

FTIA is focusing on improving information transfer and standardization by currently using LandXML and planning to adopt IFC in the future. They are working on implementing the buildingSMART Data Dictionary (bSDD) to standardize information, aiming to attach bSDD information to IFC files for better asset data readability. This initiative is in the proof-of-concept phase.

Centralized Information Storage

For centralized information storage, FTIA maintains a project database where all project information is stored, although it is not standardized. Information from completed projects is manually validated for quality before being stored. The lack of standardization poses challenges in ensuring the quality of the stored information.

Maintenance and Data Management

Maintenance and data management at FTIA involve several key practices. The process begins with cleaning up old, unnecessary data to avoid repeatedly requesting information that is no longer used. Specific personnel are assigned to manage the maintenance phase, ensuring that it is conducted based on defined contents and values. Currently, the data dictionary is primarily utilized for railway-related projects, but there are plans to extend its use to other fields such as road transport and water management. Additionally, future plans include incorporating dynamic information into BIM models to enhance their functionality and accuracy.

Integration and Training

FTIA has established a central container for project information, ensuring all data is stored in one place, even if not standardized. This process is akin to an asset information model, data management workflow, and information transfer system. They work with three major contractors, each with their own systems, which are integrated with FTIA's system to ensure automatic updates.

To prioritize data registration and reuse, the focus is on main assets critical to system functionality. Once these are calibrated, information for complementary or non-structural assets is registered based on use cases (e.g., water management, safety). FTIA aims to have BIM models for every project, necessitating comprehensive training for all involved personnel, from project managers to on-site workers, to improve data quality and integration.

Currently the predictions about maintenance schedule and costs of the asset is based on human knowledge, but FTIA believes that with standardization of information, it would be easier to take into consideration historical data, and plan the maintenance in advance with a better overview of costs.

Challenges

1. **Quality of Information**: Ensuring the quality of information is challenging due to the lack of standardization, leading to poor-quality, non-reusable data.
2. **Maintenance Data Quality**: Information provided by maintenance contractors is often of poor quality, with low incentives for uniform data provision, resulting in varied descriptions for the same items.
3. **Delayed Data Updates**: Data updates are frequently delayed, leading to incorrect information in the asset management system.
4. **Historical Data Utilization**: FTIA has not yet been able to effectively use historical maintenance data, which remains a significant challenge.

5.1.4 Belgium

In Belgium, the Agency for Roads and Traffic (AWV) employs BIM models in both design and execution phases of their projects. The primary goal is to ensure that models developed during the design phase are seamlessly transferred to the construction phase, allowing construction firms to utilize the models created by engineering firms.

Adoption and Implementation

Currently, AWV uses BIM in approximately 20 to 25% of their projects, with an aim to increase this percentage annually. However, not all projects are migrated to the BIM process due to several challenges:

1. **Resource Limitations**: AWV's team lacks the strength and resources to support the migration of all projects towards BIM. Ensuring that project managers are well-versed in BIM workflows is a priority.
2. **Market Readiness**: Engineering firms often lack sufficient BIM knowledge and resources, which must be considered in the implementation process.

Key Aspects of BIM Application

1. **OTL Standard Compliance**: Ensuring that data in BIM models comply with OTL standards is crucial for facilitating data transfer between projects and the Asset Information Model (AIM).
2. **Level of Detail (LOD)**: The appropriate level of detail for BIM models is determined based on project needs and complexity. This ensures that the right amount of data is available for necessary analyses and geometric complexity.

Information Management

AWV's information management practices are based on the ISO 19650 standard, although not followed in detail. The general process adheres to this standard, and Autodesk cloud platform services are used to support its implementation. Continuous change management, guidance, and workshops are essential to this process.

Challenges in BIM information Management

1. **Effort and Verification**: Managing BIM throughout the asset lifecycle requires significant effort for verification, follow-up, and adaptation.
2. **Data Awareness**: Employees in each phase must consider data needs for subsequent phases, even if they do not require the data themselves.
3. **Persistence and Collaboration**: Successful BIM lifecycle management demands persistent updating, collaboration, guidance, adequate budget, and ongoing awareness and data change management.
4. **Long-Term Benefits**: The advantages of BIM are not immediately apparent and may take 10 to 20 years to fully realize.
5. **File Format Support**: AWV supports eight file formats for data, which is generally sufficient. However, engineering firms use many other file formats, posing a challenge in deciding whether to support additional formats. Each new format requires in-depth analysis to understand how data is stored.
6. **OTL Compliance Integration**: Another challenge is integrating OTL compliance into software packages to make it easier for users and, ultimately, for road operators to extract the data.

By addressing these challenges and enhancing current practices, AWV aims to improve the efficiency and effectiveness of BIM implementation across all project phases.

5.2 Factors Influencing BIM process adoption

Road operators pay attention to various factors when deciding whether to integrate BIM into their systems:

- **Project Size:** Larger projects are more likely to benefit from BIM due to its potential for improved efficiency and coordination.
- **Project Requirements:** Specific project needs, such as complex design or

construction processes, can make BIM particularly valuable.

- **Business Strategies:** Road operators may adopt BIM to gain a competitive advantage in the market.
- **Real and Current Needs:** The agency's immediate needs and priorities will influence the decision to implement BIM.
- **Human Resources and Technical Capabilities:** The availability of skilled personnel and appropriate technology is essential for successful BIM implementation.
- **Data Availability:** The quality and quantity of existing data can impact the feasibility and benefits of BIM.
- **Funding and Resources:** Adequate funding is necessary to support BIM implementation, including software, training, and hardware.
- **Government Policies and Requirements:** Local and national regulations may influence BIM adoption and implementation.
- **Future Project Needs:** The potential for BIM to benefit future projects can be a factor in the decision-making process.
- **Mandatory Standards and Rules:** Road operators must comply with regional and international standards related to BIM.

By carefully considering these factors, road operators can make informed decisions about BIM implementation and maximize its benefits for their projects and organizations.

5.3 Key stakeholders

A road authority's BIM experts interact with various stakeholders throughout the lifecycle of road infrastructure projects. Effective engagement with these stakeholders ensures that BIM initiatives align with organizational goals, meet regulatory requirements, and deliver value to the public.

In Ireland, TII identifies its main stakeholders as consultants and contractors, with whom information is regularly shared. Additionally, state agencies that provide approvals on plans are crucial stakeholders in the BIM process. These interactions ensure that all necessary regulatory and technical requirements are met.

In Belgium, the AWV works closely with contractors who significantly influence decisions regarding the OTL. Internal technical experts within AWV define the parameters for data standards, while technical experts from other agencies and infrastructure managers, such as those managing waterways, contribute to these standards. The model team at AWV decides what needs to be incorporated into the BIM models and the information requirements, ensuring that all business-driven needs are addressed.

Internal stakeholders within road operators include various departments such as asset management, design and engineering, legal and compliance, and senior management. These departments play a critical role in the technical and strategic aspects of BIM implementation.

External stakeholders encompass a wide range of entities. Contractors and consultants, including civil engineering firms, architectural firms, geotechnical engineers, surveyors, and construction companies, are essential for the practical application of BIM. Government agencies, such as planning departments, environmental agencies, and transportation ministry, provide necessary regulatory oversight. The public, including residents, businesses, and community groups, are also key stakeholders, as they are directly affected by infrastructure projects. In addition, technology providers, such as BIM software developers (e.g., Autodesk, Bentley Systems, Trimble, etc.) and hardware manufacturers, ensure that the necessary tools and platforms are available and functional.

Academic institutions and research organizations, including universities and industry associations like the BIM Forum, provide research, training, and development support, helping to advance BIM practices and standards.

By effectively engaging with these diverse stakeholders, road authorities can ensure that their BIM initiatives are comprehensive, well-coordinated, and beneficial to all parties involved. This collaborative approach helps to meet organizational goals, adhere to regulatory requirements, and deliver high-quality infrastructure projects to the public.

5.4 Challenges and risks

Road operators face numerous challenges in the implementation and maintenance of BIM across their projects. These challenges span technological, organizational, and cultural aspects, impacting both internal processes and interactions with external stakeholders.

Resistance to Change and Training Needs

One of the primary challenges is convincing employees within road operators, who are accustomed to traditional processes, to adopt BIM. This resistance is also encountered among external stakeholders, including municipalities, consultancies, and local governments, who have their own established processes and data sources. Road operators must invest in extensive training and change management to demonstrate the benefits and costs of BIM, and to reorganize the external layer of stakeholders. This involves developing new processes, instructions, resources, checklists, and contracts.

Internal and External Barriers

Over the years, road operators have developed rigid processes for internal and external interactions, which stifle flexibility and innovation. Transitioning to BIM requires a period of adaptation and the promotion of BIM as a necessary innovation rather than an optional tool. Some road operators have regulatory instructions that guide data sharing and product transfer, but these are often only partial implementations of BIM or AIM processes. To achieve comprehensive BIM adoption, these processes need to be expanded and standardized at a national or international level.

Technological and Institutional Challenges

Internally, road operators face several barriers, including technological limitations, lack of communication and integration among departments, and insufficient technical skills among personnel. The organizational structure and mindset of employees also pose significant challenges. Many road operators are focused on short-term issues and daily tasks, with future needs and strategies often taking a backseat. The benefits and drawbacks of BIM, AIM, and OTL are not always clear, making it difficult to prioritize these initiatives.

Data Management and Quality

Managing BIM throughout the asset lifecycle requires significant effort for verification, follow-up, and adaptation. Employees must consider data needs for subsequent phases, even if they do not require the data themselves. Successful BIM lifecycle management demands persistent updating, collaboration, guidance, adequate budget, and ongoing awareness and data change management. The long-term benefits of BIM are not immediately apparent and may take 10 to 20 years to fully realize.

File Format and OTL Compliance

Supporting multiple file formats is another challenge. For example, AWV supports eight file formats, but engineering firms use many others, necessitating in-depth analysis of each new format. Integrating OTL compliance into software packages is also challenging, as it needs to be user-friendly and facilitate data extraction for road operators.

Quality and Standardization of Information

Ensuring the quality of information is difficult due to the lack of standardization, leading to poor-quality, non-reusable data. Maintenance data provided by contractors is often inconsistent, with low incentives for uniform data provision. This results in varied descriptions for the same items and delayed data updates, leading to incorrect information in the asset management system. Additionally, historical maintenance data is often underutilized, posing a significant challenge.

Compatibility and Interoperability

Stakeholders use different versions of software, leading to compatibility and interoperability issues. The unavailability of a CDE for many projects complicates data sharing among stakeholders. Information is often shared via emails, making it difficult to find relevant information and leading to significant time investment in locating up-to-date information. The manual approval process further scatters information and wastes time.

System Transition and Tool Selection

Convincing management about the benefits of transitioning to a new system is challenging, especially when there is a common perception that BIM is not necessary for projects. Road operators must explore appropriate tools for efficient information exchange within budget constraints.

In summary, while BIM offers many benefits, its implementation and maintenance come with significant challenges. These include resistance to change, technological and institutional barriers, data management and quality issues, file format support, OTL compliance, compatibility and interoperability, and the need for extensive training and change management. Addressing these challenges requires a concerted effort, adequate resources, and a long-term commitment to realizing the full potential of BIM.

6 Extending OTLs for Full Lifecycle Information

The CoDEC Deliverable D1a report (2020) did shed light on the OTL landscape across various road operators in 2020. As the report demonstrated, little published information on use of Data Dictionaries by road operators is available. Most road operators did not have a separately published data dictionary. Some data dictionaries were identified (England, Lithuania, Norway, Sweden, Germany) as well as other sources containing similar information (France, Australia/New Zealand). In other countries, there were no data dictionaries as such, but the road operators were developing their OTL (The Netherlands, Belgium-Flanders, Finland).

There has been quite a lot of work undertaken on the OTL aspect industry wise and individually by different road operators due to the drive towards BIM implementation on infrastructure projects. The review found that some road operators have advanced towards standardising data format and data sharing in terms of Industry Foundation Classes (IFC), but the focus of that has mainly been on data needed for construction and less so for legacy data supporting asset management.

This section aims to explore the recent developments of OTL structure within road operators with a goal to see opportunities for OTL extension to cover the full lifecycle of the asset.

6.1 Current OTL structure within road operators

The implementation and development of OTL vary significantly across different road operators. Each country has its own approach and challenges in standardizing asset data and integrating it into their BIM processes. Below is an analysis of the current state of OTL (as of August 2024) within road operators in Ireland, Belgium, Finland, and Denmark as captured during the interviews.

Ireland

Transport Infrastructure Ireland (TII) is in the process of developing data dictionaries and OTL to standardize asset data. These tools are being enriched with additional attributes based on information requirements and are intended to be used from the design phase to facilitate easy integration with the AIM. However, as of August 2024, the policy implementation for these data dictionaries is still pending. The current standards for BIM and AIM, which are 10-15 years old, are being updated to align with new information requirements. The existing data dictionaries are in the form of Excel spreadsheets listing various objects and associated attributes, but they are not based on open-source standards like Uniclass.

Belgium

The Belgium Roads and Traffic Agency (AWV) has developed a comprehensive OTL that describes all assets and their interactions throughout their lifecycle (https://wegenenverkeer.data.vlaanderen.be/). This includes data flows from hardware to software, signal flows between equipment, and asset locations on roads. The OTL is used as a step in projects, with mandatory validation and verification before any changes are made. The information is required to be OTL compliant in the projects. AWV has learned from the OTL implementations in the Netherlands and Germany, incorporating best practices into their system.

The OTL is still being expanded, particularly for civil infrastructure assets like bridges and tunnels. Feedback from internal colleagues, engineering firms, and contractors is used to continuously improve the OTL. Since OTL is used in real projects, it is easier to add missing information or make corrections in the OTL content. AWV's approach is pragmatic, starting with essential needs and ensuring backward compatibility to maintain the usefulness of existing data. The OTL is integrated across all phases of the project and since it is synchronised with actual asset data, it is considered as a static digital twin.

Regarding the process, AWV began with market research to determine how the road operators could accelerate the development of BIM and OTL implementation. A key finding was the need to develop data standards to ensure uniform communication across stakeholders from different domains. This led to the creation of the OTL. Additionally, specific file formats for models were defined, with AWV currently recommending the use of eight different formats.

AWV started applying OTL to models in 2020 through three pilot projects. However, after four years, the market was still not mature, and significant efforts were needed to ensure that previous efforts are not wasted. Significant efforts have been directed towards change management and guiding stakeholders through workshops, follow-ups, and projects. This comprehensive approach aims to ensure that all parties are well-informed and capable of adapting to the new processes. This required them to build a dedicated team who puts efforts in helping projects, validating process and guiding stakeholders.

Finland

FTIA, the Finnish Transport Infrastructure Agency, uses an open information system in the buildingSMART Data Dictionary (BsDD) for road, rail, and bridge domains (https://search.bsdd.buildingsmart.org/uri/FTIA). Their data dictionary and OTL provide verified, machine-readable information that facilitates data transfer between project phases. This system allows for the reuse of data in a standardized format and helps in tracing historical data to understand asset conditions. FTIA has developed a more comprehensive internal OTL for railway projects, focusing on construction and maintenance. BIM experts and the asset management team collaboratively define the objects and attributes in the data dictionary, standardizing information based on stakeholder requests and cleaning up the database.

Denmark

In Denmark, there are currently no standards for using object-based design or sensor data. The existing system uses a project-wise approach with a naming convention, which is considered outdated. Denmark is in the process of exploring how to move forward with ISO standards and improve their current practices. The lack of a standardized OTL poses challenges in data integration and management.

In summary, the development and implementation of OTLs within road operators are at different stages across countries. Ireland is in the early stages of policy implementation for data dictionaries and OTLs. Belgium has a well-developed and integrated OTL system that is continuously improved based on practical needs and feedback. Finland uses a machine-readable data dictionary to standardize and transfer information across project phases, focusing on construction and maintenance, however, in railway domain they have a well-defined OTL. Denmark is still exploring options for object-oriented BIM and development of OTL. Each country faces unique challenges, but all recognize the importance of standardizing asset data to enhance BIM processes and asset management.

6.2 OTL extension possibilities

The extension of OTL is a critical aspect for road operators to enhance their BIM processes and asset management capabilities. Each country has unique strategies and future plans for expanding their OTLs to include more comprehensive and dynamic information.

Ireland

Transport Infrastructure Ireland (TII) is currently developing a data dictionary tailored to the needs and requirements of the asset management department. This data dictionary has the potential to be adapted for additional information as needed. TII also considers the opinions of contractors working on-site for maintenance, incorporating their feedback into the standards. This collaborative approach ensures that the data dictionary remains relevant and comprehensive, facilitating better integration with the AIM.

Belgium

In Belgium, AWV is actively extending its OTL to cover more assets, such as bridges and tunnels. The OTL can also be expanded to include inspection data. Belgium has mechanisms to incorporate external standards, allowing the import or linking of standards related to dynamic information, such as sensor data. Currently, it is possible to link and reuse information from other OTLs, enabling the road authority to broaden its OTL using asset inventories from other domains and pre-existing information.

AWV has ongoing projects to extend their OTL to include more information, such as legal aspects and the digital interpretation of road signs. This could facilitate the incorporation of laws and policies related to various traffic assets. Although dynamic information like dynamic speed limits is not directly linked to the OTL, there is potential to integrate these systems to update the asset management system with real-time information. This integration would provide comprehensive details about asset types, locations, and current statuses. However, implementing such changes would require adherence to European standards.

Finland

Finland's FTIA is focusing on building a data dictionary and standardizing information. Once this phase is complete, they plan to explore extension possibilities. FTIA's corporate strategy emphasizes information reuse for creating digital twins in the future, which will necessitate extending their OTL. Their goal is to include dynamic information in the model, enhancing the accuracy and utility of their asset management systems.

The extension of OTLs is a crucial step for road operators to improve their BIM and asset management processes. Ireland is developing a flexible data dictionary that can be adapted based on feedback from contractors. Belgium is expanding its OTL to include more asset types and dynamic information, with a focus on integrating external standards and real-time data. Finland is standardizing information with plans to extend their OTL for future digital twin creation. Each country recognizes the importance of a comprehensive and adaptable OTL to meet evolving project needs and regulatory requirements. By continuing to develop and expand their OTLs, road operators can enhance their ability to manage infrastructure assets effectively and efficiently.

6.3 Proposed OTL structure

The implementation of an OTL for BIM information is crucial for standardizing and organizing various elements within a digital representation. An effective OTL structure ensures that the relationships between different objects are well-defined, facilitating a machine-readable and programmable interlinked information system. Here are the key components and considerations for developing a robust OTL structure:

1. **Foundation on data dictionaries**

Data dictionaries provide a strong foundation for building an OTL by establishing standard meanings, definitions, and usage of different terms and elements of infrastructure. Road operators looking to implement an OTL can leverage their existing data dictionaries as a starting point. This approach ensures that the contents and structure of the OTL are relevant to the specific requirements of the road operators.

2. Utilization of open sources

Road operators can benefit from exploring open-source libraries such as the buildingSMART Data Dictionary (bSDD) and UniClass[4]. These libraries offer predefined, classified, and interlinked assets or objects, which are continuously updated by multiple stakeholders. For instance, the Finnish Transport Infrastructure Agency (FTIA) is developing their OTL definitions within bSDD[5], ensuring that their OTL remains current and comprehensive.

3. Extension with new attributes

The extension of existing OTLs is possible by introducing new attributes that can accommodate dynamic information. This requires necessary communication with other systems, which is technologically feasible but not yet widely implemented. Ensuring that the OTL can handle dynamic data will enhance its utility and relevance for ongoing asset management.

4. Collaborative development process

The structure of an OTL should be developed collaboratively, involving inputs from multiple internal and external stakeholders, including asset management teams, designers, and contractors. This collaborative approach ensures that the OTL meets the diverse needs of all parties involved and supports effective data exchange and reuse.

5. Continuous adaptation and updating

To maintain the usability and relevance of the OTL, it is essential to continuously adapt and update its structure based on evolving requirements. Regular reviews and updates will help in incorporating new standards, technologies, and stakeholder needs, ensuring that the OTL remains a valuable tool for BIM information management.

6. Standardization and Interoperability

Standardizing the OTL structure and ensuring interoperability with other systems and platforms is critical. This includes defining clear relationships between objects and ensuring that the OTL is machine-readable and programmable. By doing so, road operators can facilitate seamless data exchange and integration across different phases of the project lifecycle.

7. Implementation of ISO standards

Adopting ISO standards, such as ISO 19650, can further enhance the effectiveness of the OTL. These standards provide a framework for managing information over the lifecycle of a built asset using BIM. Tailoring the implementation of these standards to fit local contexts while ensuring a clear understanding of their requirements can improve consistency and effectiveness.

By focusing on these key components, road operators can develop a robust and effective OTL structure that enhances the standardization, organization, and reuse of BIM information, ultimately leading to more efficient and effective asset management.

[4] https://uniclass.thenbs.com/
[5] https://identifier.buildingsmart.org/uri/FTIA/FTIA-Road/1.0

7 Reusing BIM representation for later stages

BIM information reuse is a critical aspect of modern infrastructure management, enabling the efficient use of data throughout the lifecycle of an asset. With the help of standardized data formats and classification systems, BIM information reuse ensures that valuable information generated during the design and construction phases can be effectively utilized for other purposes such as asset management or creating digital twin of road infrastructure for operation or maintenance of the project. This approach not only enhances collaboration among stakeholders but also improves data accuracy, reduces redundancy, and supports sustainable asset management practices. This section dives deeper into the current practices of BIM information reuse among road operators and associated challenges. Furthermore, an attempt is made to provide a stepwise plan for reusing BIM information.

7.1 Current process and practices around information reuse

Road operators have developed various processes and practices to ensure the effective reuse of BIM information throughout the lifecycle of infrastructure projects. These practices are crucial for maintaining data integrity, enhancing asset management, and ensuring that the built environment aligns with design intent. Below is an overview of the current processes and practices as captured via the interviews.

Ireland

Transport Infrastructure Ireland (TII) follows established standards for managing information related to the built environment, which facilitates the reuse of BIM information. The BIM team produces deliverables with the potential for efficient information reuse in mind. However, the asset management team must validate the information handed over by the BIM team to ensure that the assets are built according to the BIM models. This validation is necessary due to a lack of confidence stemming from contractors often making last-minute, undocumented changes to meet project deadlines. These changes can result in discrepancies between the built infrastructure and the design intent model.

Denmark

In Denmark, BIM models are layer-based rather than object-oriented. The information is organized in layers, which can be translated and imported into subsequent phases, but these layers do not automatically update and are not considered “smart” information. This lack of standardization can lead to misunderstandings among stakeholders and consultancies. To address this, Denmark employs layer checkers who verify the layers to identify deviations or mismatches. Stakeholders and consultancies are required to save information in predefined layers. The Danish road directorate (Vejdirektoratet) has developed local forms of BIM or AIM models that reflect project requirements, market strategies, governmental policies, and regional and international standards. However, the current methods for connections, checking, and product formats are not optimized, leading to extra effort, parallel tasks, and potential human errors. The reliance on Bentley software (DGN format) due to historical usage limits flexibility and hinders progress towards adopting other software solutions.

Belgium

The Roads and Traffic Agency (AWV) in Belgium retrieves all relevant data from BIM models during the operations phase and stores it in an asset database. This includes basic geometry such as point, line, or polygon data, which remains connected to the assets in the database. However, the BIM models are no longer updated and cannot be used as the source of truth. Instead, all necessary information is extracted and stored separately in the asset database.

The data undergoes a two-step validation and verification process. The validation phase involves automatically checking OTL compliance for the complete dataset, while the verification phase involves project managers or site leaders sampling the data to verify its content. Following these steps, data quality reports are produced to identify areas for improvement. The asset database is then used by both internal colleagues and maintenance contractors.

Belgium has also conducted a proof-of-concept project in a tunnel, integrating data from asset inventory and real-time sensor data to create a digital twin. AWV considers their asset inventory as a digital twin, synchronized with the actual reality of physical assets. This pilot project demonstrated that their asset management system could be extended with real-time data, enhancing the overall management of infrastructure assets.

Finland

Finland is concentrating on extending BIM usage beyond construction, aiming to improve the transfer of information from Project Information Models (PIM) to Asset Information Models (AIM) through a standard known as Infra Model. Currently, LandXML is used for information transfer, but there are plans to adopt Industry Foundation Classes (IFC) as the information delivery container in the future. Direct information exchange from PIM to AIM is not yet possible, but FTIA is working on implementing the buildingSMART Data Dictionary (bSDD) to standardize information. The goal is to attach bSDD information to IFC files, enabling the reading of asset data. This initiative is in the proof-of-concept phase, focusing on practical aspects of data sharing.

FTIA emphasizes the importance of having all project information centrally stored to facilitate information reuse. They maintain a project database (not a CDE) where all project information is required to be stored. Although the information is not standardized, the storage has a structured format. Information from completed projects is manually validated for quality before being stored in the database. However, the lack of standardization poses challenges in ensuring the quality of information.

Additionally, FTIA focuses on the immediate reuse of specific elements from BIM models to enhance asset management. Key reusable elements include road addresses and locations, safety-related attributes such as the maximum load on a bridge, and speed limits. By reusing these elements, FTIA ensures that critical information is preserved and utilized throughout the asset lifecycle, enhancing the overall efficiency and safety of infrastructure management.

The reuse of BIM information by road operators involves a combination of validation, verification, and integration processes to ensure data accuracy and utility. Ireland focuses on validating BIM information to align with design intent, Denmark uses layer-based models with predefined layers for information organization, Belgium employs a comprehensive validation and verification process to maintain an accurate asset database and Finland is working on standardizing information transfer and centralizing project data. These practices highlight the importance of standardization, systematic data management, and the potential for integrating real-time data to enhance asset management.

7.2 Reusable elements

All interviewed road operators have mentioned that there are various components within their BIM digital representations that can be effectively reused for asset management and the development of Digital Twins. Standardizing processes and data are crucial for the seamless migration of information from PIM to AIM. Implementing OTL from the early stages of a project or asset lifecycle helps streamline workflows and facilitates easier migration.

The elements that need to be recycled from BIM to AIM or DT can vary between organizations and must be identified in consultation with the asset management team and their stakeholders based on specific requirements. Harmonizing processes and systems between BIM and AIM teams is essential. Denmark emphasizes the importance of communication between these teams to ensure that valuable information is identified and effectively transferred. From a technology perspective, it is easier to migrate the data from BIM digital representation to Asset teams (Denmark, Belgium), however, it is important to identify which information is valuable for the asset management team. Establishing information management processes in line with ISO 19650 can help eliminate standardization issues, improve data quality, and address communication challenges.

In Belgium, the Roads and Traffic Agency (AWV) has developed a protocol for using various types of modelling software such as Civil 3D, Revit, and IFC files. These protocols support any kind of asset and describe how to classify them according to the OTL. Once classified, relevant information is extracted from the BIM models and integrated into the AIM. This ensures that all necessary data is systematically organized and readily available for asset management purposes. The classification according to the OTL is a mandatory step, ensuring consistency and standardization across all projects.

Finland's FTIA focuses on the immediate reuse of specific elements from BIM models to enhance asset management. Key reusable elements suggested during the interview are:

- **Road Addresses and Locations**: These elements can be directly reused, providing accurate geographical data for asset management.
- **Safety-Related Attributes**: Information such as the maximum load on a bridge is crucial for maintaining safety standards and can be reused effectively.
- **Speed Limits**: These can also be reused, ensuring that traffic regulations are consistently applied and managed.

By reusing these elements, FTIA ensures that critical information is preserved and utilized throughout the asset lifecycle, enhancing the overall efficiency and safety of infrastructure management.

The reuse of BIM information involves identifying and standardizing key elements that can be effectively transferred from PIM to AIM or DT. Belgium's AWV ensures that all relevant information is classified according to the OTL and extracted from BIM models for integration into AIM. Finland's FTIA focuses on reusing specific elements such as road addresses, safety-related attributes, and speed limits. These practices highlight the importance of standardization, systematic data management, and effective communication between BIM and AIM teams to enhance asset management and the development of Digital Twins. By adopting these practices, road operators can improve the accuracy, reliability, and efficiency of their asset management processes.

7.3 Challenges in information reuse

The reuse of Building Information Modelling (BIM) data presents several challenges across different countries and contexts. These challenges can be broadly categorized into issues related to integration, standardization, software dependency, and information quality.

Integration and System Compatibility

In Ireland, the primary challenge lies in integrating different types of systems for various assets. While the BIM team can deliver information effectively, the lack of a unified system makes it difficult to bring everything together. This fragmentation hinders the seamless transfer of data from one phase to another, complicating the overall asset management process.

Standardization and Layer Management

Denmark faces significant challenges with ensuring designers use the correct layers. The use of layers instead of OTL means that information is not automatically updated, leading to potential misunderstandings among stakeholders. To mitigate this, layer checkers are employed to find deviations or mismatches, but this adds extra effort and potential for human error.

Software Dependency

The dependency on specific software, such as Bentley in Denmark, restricts the ability to adopt new technologies and improve processes. This software lock-in prevents the use of more flexible or advanced tools that could enhance BIM data management and reuse.

Implementation of ISO 19650

Implementing ISO 19650 for road infrastructure data exchange presents its own set of challenges. The standard is not uniformly understood or applied across different countries, leading to inconsistencies. Each country or company may follow historical methods, requiring tailored processes that do not fit a one-size-fits-all approach. Outdated platforms further complicate the adoption of ISO 19650, necessitating a move towards more modern solutions.

Data Quality and Maintenance

Maintaining up-to-date information is a recurring challenge. In Finland, the quality of information is often poor and non-standardized, making it difficult to reuse. Similarly, in Denmark, the information in the AIM is sometimes outdated, requiring external consultancies to update it. Ensuring that data attributes in CAD models are relevant for asset management is crucial but often overlooked.

Training and Change Management

In Belgium, road authorities need to train contractors to create BIM models, as many are accustomed to working with 2D drawings or Excel files. This transformation is easier for some contractors but remains challenging for many. Standardizing asset types further would facilitate easier data extraction. The main challenge here is managing change and organizational adaptation to new processes.

Recommendations for Mitigation

To address these challenges, several strategies can be employed:

- **Standardization**: Developing and adopting standardized forms of information and processes can reduce misunderstandings and improve data quality.
- **Training and Education**: Providing comprehensive training for all stakeholders, including contractors and designers, can ease the transition to BIM and improve data accuracy.
- **Software Flexibility**: Encouraging the use of flexible software solutions that are not locked to specific formats can enhance adaptability and innovation.
- **ISO 19650 Implementation**: Tailoring the implementation of ISO 19650 to fit local contexts while ensuring a clear understanding of its requirements can improve consistency and effectiveness.
- **Regular Updates and Maintenance**: Establishing protocols for regular updates and maintenance of BIM data can ensure that information remains current and useful for asset management.

By addressing these challenges through a combination of standardization, training, and flexible software solutions, the reuse of BIM information can be significantly improved, leading to more efficient and effective asset management.

7.4 Proposed process of reusing BIM information

To create a process for BIM information reuse, we integrated the best practices and lessons learned from Ireland, Denmark, Belgium, and Finland. Here's a proposed structured approach that can be followed to facilitate BIM information reuse. However, road operators may need to follow a different approach based on their BIM maturity and current practices:

a. **Define objectives and scope**
   Identify the goals of BIM reuse, such as reduce data capture for later stage of asset lifecycle, create digital twin, improve asset management etc. Define the scope by considering the data availability, requirements, and the stakeholders involved. In addition, take into account the budget and capabilities of the team.

b. **Establish standards and guidelines**
   - **BIM standards:** Create or adapt existing BIM standards and guidelines that specify the requirements for data exchange, level of detail, and format (e.g., IFC, openBIM standards).
   - ***Adopt ISO 19650****:* Implement ISO 19650 as the framework for information management and exchange throughout the project lifecycle.
   - ***Develop (or use) OTL***: Create or use a detailed OTL that defines the properties and attributes of each asset type. This will ensure consistency and interoperability across different projects and organizations.
   - ***Standardize Data Formats:*** Define and use standardized data formats (e.g., Industry Foundation Classes (IFC), Information Delivery Specification (IDS) etc.) to facilitate information exchange and integration. Open standards like IFC and bSDD can ensure interoperability between different software tools and platforms.

c. **Establish collaboration and communication procedure**
   - **Interdepartmental Collaboration:** Foster active collaboration between BIM and AIM departments to ensure mutual understanding of requirements and capabilities.
   - **Stakeholder Engagement:** Conduct workshops and collaborative meetings to address inconsistencies, challenges, and extract a common language for processes.
   - **Simplify Processes**: Simplify communication and information delivery processes to make them more efficient and effective.

d. **Identify information requirements**
   - **Define Information Requirements:** Collaborate with stakeholders to identify and document various information requirements (organisational, asset, project and exchange) as shown in Figure 12 for each asset from the design stage.
   - **Prioritize Information:** Prioritize the information based on its criticality to asset performance and lifecycle management.
   - **Align with OTL:** Ensure that the identified information requirements align with the OTL to ensure consistency and data quality.

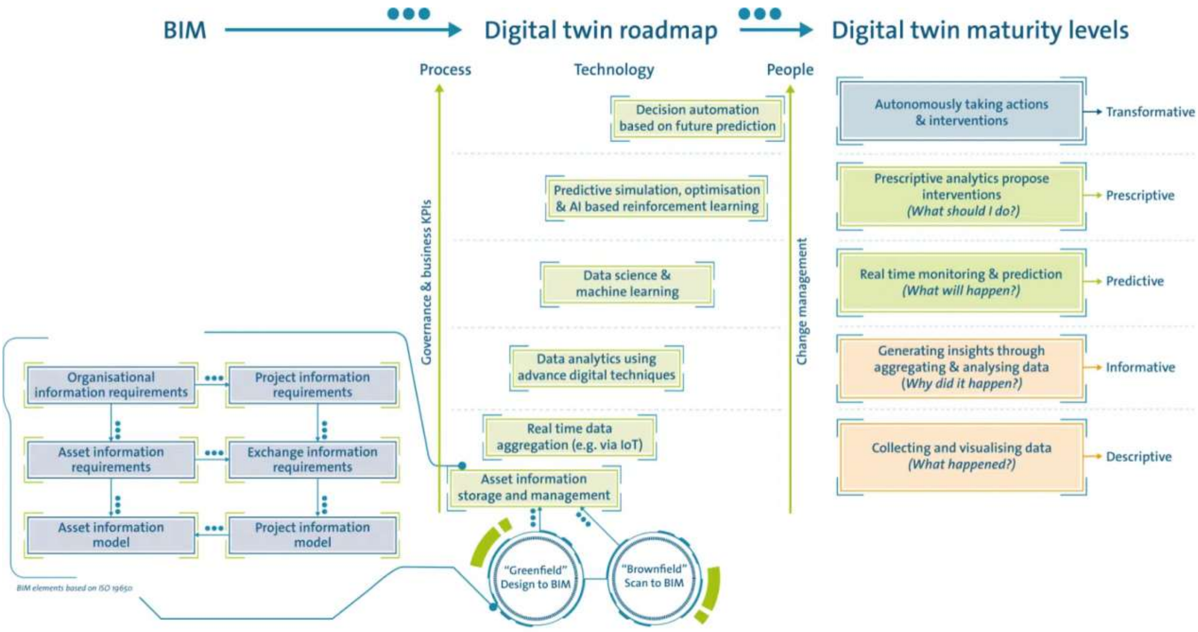

Figure 12: Process of transition from BIM to Digital twin (©2020 Royal HaskoningDHV)

e. Facilitate data/information exchange

- **Data Governance Framework:** Establish a framework for data ownership, access, and sharing, including data security and privacy protocols. Define roles and responsibilities for data management across the asset lifecycle, from planning through operation. Data Governance is further covered under DROIDS deliverable D5.1.
- **Utilize CDEs**: Implement a CDE to facilitate secure data sharing and collaboration across stakeholders. Ensure the CDE supports integration with existing systems and allows for data validation and quality assurance.
- **Establish Data Transfer Protocols:** Define clear protocols for transferring BIM data between different stakeholders, including designers, contractors, and asset managers.

f. Integrate BIM into design processes

- **Collect and standardize BIM data:** For past and current projects, gather BIM data, ensuring it meets the standards. Validate the quality of the data, and fill in missing or incomplete information, where feasible.
- **Incorporate BIM from Early Stages:** For new projects, start using BIM from the initial design phase to capture detailed information about assets.
- **Link BIM Models to OTL:** Associate BIM elements with corresponding OTL objects to ensure data consistency and traceability.

g. Ensure data quality and accuracy

- **Implement Quality Control Procedures**: Establish quality control procedures to verify the accuracy and completeness of BIM data.
- **Validate Data against OTL**: Regularly validate BIM data against the OTL to ensure compliance with standards and requirements.
- **Conduct Data Audits:** Perform periodic data audits to identify and correct errors or inconsistencies.

h. BIM to Asset Management Systems

- **Develop Data Migration Strategies:** Develop strategies to migrate existing asset information from BIM models to asset management system, ensuring data consistency and completeness.
- **Integrate BIM with Asset Management Systems:** Integrate BIM data to asset management systems to enrich information and reduce need for data capture during operational phase.

i. Data Management and Maintenance

- **Continuous Data Update**: Ensure that asset data is kept up-to-date and accurate throughout the asset lifecycle, especially during maintenance phases.
- **Quality Assurance**: Implement mechanisms for validating and verifying data quality to maintain trust and reliability.

j. Change management

- **Gradual Implementation:** Start with pilot projects to test and refine BIM processes. Use feedback and lessons learned to update standards, policies, and processes gradually.
- **Address Organizational Barriers:** Overcome organizational barriers, such as resistance to change and lack of resources, to facilitate BIM information reuse.
- **Training and Awareness:** Organise trainings for internal and external stakeholders on using BIM data effectively within the established standards and systems. Promote awareness of the benefits of BIM reuse and how it supports decision-making and improves project outcomes.
- **International Collaboration:** Exchange knowledge and best practices with other countries to stay updated on advancements and improvements in BIM/OTL implementation and information reuse.

k. Monitoring and Evaluation

- **Regular Assessments**: Conduct regular assessments to evaluate the effectiveness of BIM implementation and information reuse and make necessary adjustments. Necessary KPIs can be defined to measure performance and maturity.
- **Feedback Loop**: Establish a feedback loop to continuously improve processes based on stakeholder input and project outcomes. Also, ensure that stakeholders are informed of changes and improvements.
- **Scaling**: Plan to expand BIM reuse capabilities for more extensive national infrastructure projects, adjusting for scalability.

By following these steps, road operators can effectively reuse BIM information, ensuring a unified, interoperable, and efficient system for managing road assets.

However, It's crucial to understand that the primary focus should be on change management rather than solely on developing data standards or investing in new technologies like software or applications. Change management represents the most significant investment, with benefits typically realized over a long period—around 10 years if high-quality asset data is available, and potentially 15-20 years if it is not as reported by AWV in Belgium-Flanders.

AWV highlighted the importance of change management because it introduces new processes that stakeholders are unfamiliar with. This requires substantial data standardization efforts, generally necessitating a dedicated team to support projects, validate processes, and guide stakeholders. Training and skill development are also essential to prepare both internal and external stakeholders for future data usage. While legal requirements can aid this transition, they are insufficient without a strong focus on change management.

8 Conclusion and recommendations

This deliverable aimed to explore the potential of using BIM information for a digital twin addressing the entire lifecycle of road infrastructure. The potential to reuse BIM information in later stage of the asset such as asset management, decision making or to create a digital twin of the road infrastructure can benefit in reduction of new data capture and help create a more cohesive and informed digital representation. Furthermore, the developments within road operators regarding OTL was also examined which standardises the asset information and can help migration of asset information from BIM representation to asset management systems and later to digital twin. At the end, a stepwise approach for information reuse was proposed which could help road operators further with reuse of the information.

In order to gather information, a literature review was carried out to understand the state of the art of BIM and OTL implementation. Furthermore, interviews with BIM experts within road operators was carried out to understand their practices and challenges within their organisation.

Based on the information gathered from the research and interviews, the deliverable’s sub research questions mentioned in section 2 are reviewed below. Based on the answers from the sub research questions, the main research questions with recommendations are then answered at the end of this chapter.

What are the current practices in relevance to the management of BIM information within NRAs?

Road operators across Europe are increasingly adopting BIM to streamline project delivery, enhance collaboration, and optimize asset management. While the level of implementation varies among countries, several common practices are emerging.

Most road operators are still in the early stages of BIM maturity, with a few reaching a level of integration where BIM activities are developed, embedded, and becoming effective. Road operators typically rely on a mix of traditional and modern data collection methods, including visual inspections, machine surveys, and remote sensor data. However, the lack of a unified method for data standardization and the separation of asset management divisions hinder the development of a full lifecycle BIM system.

Road operators like TII in Ireland are focusing on developing policies and standards for BIM implementation, with a particular emphasis on data standardization and integration. However, challenges such as manual approval processes, limited data sharing capabilities, and a lack of a centralized data environment hinder efficient information management.

In Denmark, BIM is used primarily for 2D and 3D object-based models, primarily using Bentley software. While 3D and 2D models are archived for asset management, they are often insufficient. To enhance accuracy, Point Cloud to BIM or 3D scanning to BIM techniques are employed. However, there is a disconnect between models used in different project phases, and the lack of data dictionaries limits data standardization.

In Finland, the FTIA focuses on improving information transfer and standardization using LandXML and planning to adopt IFC. They are implementing the buildingSMART Data Dictionary (bSDD) to standardize information. FTIA maintains a centralized project database but faces challenges in ensuring data quality and timely updates.

Belgium's AWV employs BIM in design and execution phases. The goal is to seamlessly transfer models from the design to construction phase. However, resource limitations and market readiness hinder full-scale BIM adoption. AWV adheres to the ISO 19650 standard and uses Autodesk cloud platform services. Challenges include effort and verification required for lifecycle management, data awareness, and long-term benefits.

Road operators consider various factors when deciding on BIM integration, including project size, requirements, business strategies, real needs, human resources, data availability, funding, government policies, and future project needs.

Who are the key stakeholders involved in the maintenance of the road infrastructure and what are their information needs?

The maintenance of road infrastructure involves a diverse range of stakeholders, each with specific information needs. <the road operators' internal stakeholders, such as asset management, design and engineering, legal and compliance, and senior management, require data on asset condition, design details, regulatory compliance, and overall network performance. External stakeholders, including contractors, consultants, government agencies, the public, technology providers, and academic institutions, need information on project specifications, regulatory requirements, construction timelines, software and hardware solutions, and research data. By effectively engaging with these stakeholders and sharing relevant information, road operators can optimize maintenance activities, reduce costs, and improve the overall performance of the road network.

How do current NRAs' Object Type Libraries (OTLs) structure and store information relevant to road infrastructure?

The implementation and development of OTL vary significantly across road operators in different countries. Ireland is in the early stages of developing data dictionaries and OTLs to standardize asset data, with policy implementation still pending. Belgium has a comprehensive and integrated OTL system that is continuously improved based on feedback and practical needs. Finland uses a machine-readable data dictionary to standardize and transfer information across project phases, with a well-defined OTL for railway projects. Denmark, however, is still exploring options for object-oriented BIM and the development of OTL, facing challenges due to the lack of standardized practices. Rijkswaterstaat in the Netherlands has a clear, well defined and comprehensive OTL.

The structure of existing OTL from the Netherlands (https://otl.rws.nl/) and Belgium (https://wegenenverkeer.data.vlaanderen.be/) can be found in their respective websites.

How can NRAs' OTLs be extended or modified to accommodate information relevant to the entire lifecycle?

To extend or modify road operator's OTLs to accommodate information relevant to the entire lifecycle of assets, it is crucial to incorporate feedback and foster collaboration among all stakeholders. This includes gathering continuous input from contractors, maintenance teams, and asset managers to ensure the OTL remains comprehensive and relevant. Expanding the OTL to cover a wider range of assets, such as bridges and tunnels, and integrating inspection and maintenance data will provide a complete view of the asset's condition and history. Additionally, incorporating dynamic information from sensors and other real-time data sources will keep the asset information up-to-date, allowing for real-time updates that reflect current statuses, such as dynamic speed limits and traffic conditions.

Standardization and interoperability are essential for the successful extension of OTLs. Adopting open standards like Uniclass or bSDD ensures that the OTL is future-proof and can interoperate with other systems. Including legal and regulatory information in the OTL will ensure compliance with national and international standards, while regular updates to reflect changes in laws and policies will keep asset management practices compliant. Focusing on change management, providing ongoing training, and establishing dedicated teams to manage the OTL will support these efforts.

What are the current practices regarding the reuse of BIM information within NRAs?

Since many road operators are in the earlier stage of BIM adoption and implementation, reuse of BIM information often remains a challenge. Road operators often need manual intervention when the information from PIM need to migrate to AIM or asset management systems (Ireland, Finland, Denmark). This often involve manual validation and verification of digital information in BIM models from built asset, as there are sometimes undocumented changes in the last phase of construction, which differs from the design intent model.

Road operators have developed various practices to manage and reuse BIM information effectively. Ireland focuses on validating BIM information to align with design intent. In Denmark, since the digital representation uses layer-based approach, manual interventions are needed to validate if the information is stored in correct layer which is performed by dedicated team of layer checkers. On the other hand, Belgium employs a comprehensive validation and verification process to maintain an accurate asset database. In Belgium, the data from BIM models are validated automatically to ensure that its OTL compliant before moving it in asset management system. Finland is working on standardizing information transfer and centralizing project data. By adopting these practices and prioritizing data quality, road operators can improve asset management and decision-making.

Which specific elements within BIM representations can be identified and recycled for use in Asset Information Modelling (AIM) and Digital Twin (DT)?

BIM models contain a lot of useful of information that can be recycled for AIM and digital twin (DT) development. Key elements that can be reused include geometric data such as road alignments, bridge geometry, and tunnel details. Attribute data like material specifications, load capacities, and maintenance records can also be transferred. Spatial data, including geographic coordinates and asset relationships, is crucial for accurate location-based information. Additionally, non-geometric data like asset identification numbers, construction dates, and regulatory compliance information can be leveraged.

Although a lot of information can be reused, the main challenge lies in the standardisation of information. Implementation of BIM workflow along with OTL for structuring asset information from the design state of an asset's lifecycle helps facilitate easy reuse of information.

What processes can be developed to effectively recycle BIM representations throughout the full lifecycle of digital twins for road infrastructure?

To effectively recycle BIM representations throughout the full lifecycle of digital twins for road infrastructure, road operators can implement the process as outlined in section 7.4:

a. *Define Objectives and Scope:* Clearly define the goals and scope of BIM reuse, considering data availability, requirements, and stakeholders.
b. *Establish Standards and Guidelines*: Develop and adopt BIM standards, ISO 19650, and OTLs to ensure consistency and interoperability.
c. *Establish Collaboration and Communication*: Foster collaboration between BIM and AIM teams, engage stakeholders, and simplify processes.
d. *Identify Information Requirements*: Define and prioritize information requirements aligned with OTL.

e. *Facilitate Data Exchange:* Implement data governance, utilize CDEs, and establish data transfer protocols.
f. *Integrate BIM into Design Processes:* Collect and standardize BIM data, incorporate BIM from early stages, and link BIM models to OTL.
g. *Ensure Data Quality:* Implement quality control procedures, validate data against OTL, and conduct data audits.
h. *Integrate BIM with Asset Management Systems:* Develop data migration strategies and integrate BIM data to enrich asset management systems.
i. *Data Management and Maintenance:* Ensure continuous data updates, quality assurance, and effective change management.
j. *Monitoring and Evaluation:* Conduct regular assessments, establish a feedback loop, and plan for scaling.

By following these steps and prioritizing change management, road operators can successfully reuse BIM information to enhance asset management and digital twin development.

Based on the answers from the sub research questions, the following main research questions with recommendations are then answered.

(RQ10) How should the [BIM] information be maintained throughout the life cycle of the road infrastructure, given the many different stakeholders involved in the maintenance of the physical infrastructure?

In order to maintain the BIM information throughout the lifecycle of road infrastructure, road operators have recommended following considerations:

- **Implement ISO 19650**: Implement ISO 19650 as the framework for information management and exchange throughout the project lifecycle.
- **BIM standards:** Create or adapt existing BIM standards and guidelines that specify the requirements for data exchange, level of detail, and format (e.g., IFC, openBIM standards).
- **Develop and implement OTL**: Create or use a detailed OTL that defines the properties and attributes of each asset type. This will ensure consistency and interoperability across different projects and organizations.
- **Establish collaboration and communication:** Active collaboration between internal stakeholder such as BIM and AIM departments ensures mutual understanding of requirements and capabilities. On the other hand, collaboration with external stakeholders such as contractors, design and engineering firms, consultants, technology providers etc helps in identifying information requirements and ensuring the needs of every stakeholder.

(RQ11) Could the NRAs' OTLs (Object Type Libraries) be extended to cover information for the full life cycle?

As discussed with BIM and OTL experts within the interviewed road operators, it was found that their OTLs could be extended to cover information for the full lifecycle of assets. In fact, some road operators (Belgium and Finland) already have plans to extend their OTL with more asset types and dynamic information for future digital twins and asset maintenance. However, many road operators are in an early stage of BIM implementation and does not have an OTL implemented yet. In order to reap the benefits of standardisation emerging from OTL implementation and possible extension, road operators could consider the following key components:

- *Data Dictionary Foundation:* Build upon existing data dictionaries to establish standard definitions and meanings.
- *Leverage Open Sources:* Utilize open-source libraries like bSDD and Uniclass to establish a solid foundation and ensure continuous updates.
- *Extend with New Attributes:* Incorporate new attributes to accommodate dynamic information and future needs.
- *Collaborative Development:* Involve multiple stakeholders to ensure the OTL meets diverse needs and facilitates data exchange.
- *Continuous Adaptation:* Regularly review and update the OTL to adapt to evolving requirements and technologies.
- *Standardization and Interoperability:* Ensure the OTL is standardized and interoperable with other systems and platforms.
- *ISO Standards Implementation:* Adopt ISO 19650 to provide a framework for information management and exchange.

By following these principles, road operators can create a powerful OTL that supports efficient BIM information management and enhances asset lifecycle management.

(RQ 9) How, and to what degree, can BIM representations be reused for other purposes in the later stages (AIM and ITS) to reduce the need for new data capture for NRAs and Map Providers?

The BIM representation contains lot of valuable information that can be repurposed for asset management or creation of digital twin of road infrastructure. Section 7.4 proposes the process of maintaining and reusing BIM information that can be adopted by road operators to enable standardised flow of information and efficient use of BIM information. Various steps that can be taken by the road operators include defining objectives and scope, establishing standards and guidelines, enabling collaboration and communication, identifying information requirements, facilitating data exchange, integrating BIM into design processes, ensuring data quality, integrating BIM with AMS, data management and maintenance, and monitoring and evaluation. These steps may vary between various road operators based on their BIM maturity and pre-established organisational processes.

The degree of reusing BIM information also depends on the maturity of the road operators. Since many road operators are at an earlier stage of BIM implementation, there is a lack of useful digital representations, from which information can be reused. For example, in Belgium, BIM process is followed merely in 20-25% projects. This number is even lower in other countries where BIM process is considered for only large-scale projects. Furthermore, even when the projects follow a BIM process, lack of implementation of standardised and comprehensive object type libraries makes it difficult to easily transition data due to different formats being used by different departments and their systems with road operators.

Thus, to improve the BIM information reuse, road operators should implement BIM standards within their organisation for information management and try implementing an OTL to provide structure to asset information. European policies for standardised OTL such as EuroOTL as described in previous CEDR INTERLINK project, would be helpful in ensuring that different organisations can work together with each other and use common resources.

In summary, this deliverable explored the potential of reusing BIM information for digital twins throughout the lifecycle of road infrastructure. The research highlights the significant benefits of BIM information reuse, including reducing the need for new data capture, improving data quality, and facilitating better decision-making. However, challenges such as a lack of standardization, software dependency, and data quality issues currently hinder effective reuse.

The deliverable recommends a stepwise approach for road operators to address these challenges and improve BIM information reuse. This approach emphasizes standardization through the use of ISO 19650 and OTLs. It also highlights the importance of collaboration, training, and the adoption of flexible software solutions. By implementing these recommendations, road operators can unlock the full potential of BIM information reuse, leading to more efficient and effective asset management practices.

Further research is recommended to explore the integration of BIM with real-time sensor data and the development of standardized OTLs that encompass the entire lifecycle of road assets. This will pave the way for the creation of robust digital twins that can continuously monitor and optimize the performance of road infrastructure.

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Appendix A: Interview questions

I. BIM Representations & Reuse

1. **Current Use:**
    - To what extent do you use BIM models in your road infrastructure projects?
    - How does your organization currently use BIM representations in the design and construction phases of road infrastructure projects?
    - How is BIM information currently leveraged to create Asset Information Models (AIM) or Digital Twins (DT)?
    - What specific elements within your BIM models do you believe could be reused or repurposed for asset information management (AIM) and DT in the later stages of the lifecycle?

2. **Data Transfer & Standards:**
    - What are the challenges in transferring BIM data in a structured format from the design stage to the operational stage for use in digital twins?
    - How familiar is your organization with the ISO 19650 standard? To what extent do you believe it can facilitate data exchange and management throughout the asset lifecycle?
    - Are there specific challenges in implementing ISO 19650 for road infrastructure data exchange?

3. **Object Type Libraries (OTLs):**
    - How does your organization use OTLs? What are the strengths and limitations of your current OTLs in capturing information relevant to the full lifecycle of road infrastructure?
    - Could you envision extending your OTLs to include information relevant to AIM and ITS? What specific data elements would you prioritize for inclusion?
    - What data exchange formats are used with your current OTLs? How can interoperability with other BIM software be ensured?
    - Need for standard OTL across countries?
    - Data dictionaries present?

4. **Recycling Process & Risks:**
    - In your ideal scenario, what would a process for recycling BIM representations across the entire lifecycle of a digital twin look like?
    - What potential risks or challenges do you foresee in implementing such a process? (e.g., data compatibility, software issues, stakeholder coordination)

5. **Value & Benefits:**
    - What do you see as the primary benefits of reusing BIM data for AIM and DT purposes? (e.g., reduced data capture efforts, improved data accuracy, enhanced decision-making)
    - Are there any specific use cases or examples where you have successfully reused BIM data beyond the design and construction stages? Or Enriched BIM with other datasets?
    - How would you measure the success of a BIM data reuse process for digital twins (e.g., cost savings, time efficiency)?
    -

II. Information Maintenance & Stakeholder Coordination

1. **Stakeholders & Responsibilities:**
    - Who are the key stakeholders involved in maintaining the road infrastructure throughout its lifecycle? How do their information needs and responsibilities differ? (it can be external but also internal divisions such as asset management department for road, bridges, tunnels etc.)
    - What mechanisms or platforms do you use to facilitate communication and data sharing among these stakeholders?

2. **Existing Data Management Workflows:**
    - Briefly describe your organization's current data management workflows for road infrastructure (e.g., data collection, storage, access).
    - How would integrating BIM data reuse fit within these existing workflows?
    - What adjustments or improvements would be needed to facilitate smooth integration?

3. **Data Updates & Accuracy:**
    - How do you ensure that the information in your BIM models or digital twins remains up-to-date and accurate as the physical infrastructure changes over time?
    - What are the challenges in keeping this information current, and how could they be mitigated

4. **Lessons Learned:**
    - What lessons has your organization learned about information management and stakeholder coordination in the context of road infrastructure projects?
    - Are there any best practices or approaches that you would recommend to other organizations?

5. **Future & Skills**
    - What training or skills development is needed for personnel to effectively use BIM data across the lifecycle?
    - What are your thoughts on the future evolution of BIM for managing road infrastructure data throughout its lifecycle?