Building Information Modeling (BIM) Practices in Highway Infrastructure

March 2021

FHWA Global Benchmarking Program Report

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Federal Highway Administration

FOREWORD

There is currently steady and growing use of innovative digital technologies to design and construct capital highway projects and to monitor their condition and performance. Building Information Modeling (BIM) is gaining rapid acceptance in several infrastructure industries, including highway transportation. BIM, as applied to highway infrastructure (referred to in this report as BIM for infrastructure), involves delivering capital projects collaboratively (through the planning, design, and construction phases) and managing services the built infrastructure is expected to provide efficiently using digital processes rather than traditional paper-based processes. By aligning data within and across an agency's information systems in a manner that allows them to be managed easily, the potential exists to break down information silos and offer major productivity gains and cost efficiencies for Departments of Transportation (DOTs) across all life-cycle phases of built infrastructure. While Federal Highway Administration (FHWA) has led efforts to foster greater use of digital work processes, tools and technologies with the goal of improving safety, quality, and productivity of highway project and service delivery, there are lessons to be learned from countries also undergoing this digital transformation.

This report documents evolving trends in BIM implementations in BIM-mature nations and their public highway infrastructure agencies, with a focus on understanding how other countries are using BIM for infrastructure to better deliver transportation projects, manage assets, and provide related services with a view to benchmark and advance U.S. practice. Visits were made to BIM-mature agencies in the United Kingdom, the Netherlands, and Norway to discuss and examine core aspects of BIM for infrastructure implementation in greater depth. The BIM development efforts of the studied agencies demonstrated clear motivation, purpose, goals, and top-line support, which recognize both the costs, and more importantly, the benefits of adopting BIM for infrastructure. The officials visited offered the study team invaluable advice related to priority activities to focus on and key international efforts to follow in this fast-developing field. This report which documents noteworthy BIM practices and translatable lessons learned from these countries and benefits realized by them should be a helpful resource to the US highway industry.

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16. Abstract

Once considered just for buildings, Building Information Modeling (BIM) is gaining rapid acceptance in several infrastructure industries, including highway transportation. BIM, as applied to highway infrastructure (referred to in this report as BIM for infrastructure), involves delivering capital projects collaboratively (through the planning, design, and construction phases) and managing services the built infrastructure is expected to provide efficiently using digital processes rather than traditional paper-based processes.

The movement toward BIM for infrastructure has been growing in the United States (U.S.) and is becoming more widely used by industry, including engineers, planners, contractors, and owners. Despite these developments, progress related to BIM implementation in the highway infrastructure arena has been slow in the U.S. compared to other industries (e.g., buildings). This study was conducted on behalf of FHWA's Global Benchmarking Program (GBP) to document evolving trends in BIM implementations in BIM-mature nations and their public highway infrastructure agencies, with a focus on understanding how other countries are using BIM for infrastructure to better deliver transportation projects, manage assets, and provide related services with a view to benchmark and advance U.S. practice.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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List of Acronyms

AASHTO	American Association of State Highway and Transportation Officials
Bane NOR	Norwegian Railway Infrastructure Managers
BEP	BIM execution plan
BIM	Building Information Modeling
CDE	common data environment
CEDR	Conference of European Directors of Roads
CFR	Code of Federal Regulations
DBFM	Design-build-finance-maintain
DOT	Department of Transportation
DRD	Danish Road Directorate
FHWA	Federal Highway Administration
FTIA	Finnish Transport Infrastructure Agency
GBP	Global Benchmarking Program
GIS	geographic information system
GML	Geography Markup Language
IFC	Industry Foundation Classes
IDS	Information Delivery Specifications
IT	Information Technology
NPRA	Norwegian Public Roads Administration
OGC	Open Geospatial Consortium
O&M	operations and maintenance
R&D	research and development
RDF	Resource Description Framework
RWS	Rijkswaterstaat

Executive Summary

Introduction

Building Information Modeling (BIM) is rapidly gaining acceptance in several infrastructure industries, including highway transportation. However, some agencies have begun to deemphasize the term "BIM" in their specifications as it is interpreted in different ways by different people and the focus shifts from the real intent of the term. There is a growing recognition that BIM, as applied to highway infrastructure (referred to in this report as BIM for infrastructure), involves collaboratively delivering capital projects using digital processes that organize and move data and information efficiently through the planning, project delivery, and operation and maintenance phases. The so-called "open BIM processes," which allow data interoperability between various software applications used to design, build, maintain, and operate infrastructure, optimize traditional asset lifecycle management workflows; prevent information loss and duplication; and replace paper outputs and deliverables. Asset owners adopting this modern, digital way of doing business are reaping benefits in terms of cost, time savings, and safety.

At its core, BIM is about driving value from enhanced data management techniques regarding assets and asset networks. It involves creating (modeling) and sharing data and information across various lifecycle data systems (e.g., design, construction, asset management) using accepted standards, maintaining quality, and cataloging it in a manner that makes it easier to find and work with (i.e., creating metadata) for both humans and machines. To ensure continuity of data and information exchange, in the open lifecycle BIM approach, data stored within the various lifecycle systems have to first be aligned. A key component of open BIM, therefore, is the ability to model[1] and share data seamlessly across multiple software applications using a standard and open (as opposed to a proprietary) format (e.g., Industry Foundation Classes or IFC; CityGML, InfraGML, LandXML, etc.). The specific modeling and exchange standards and formats utilized depend on the asset lifecycle phase and the requirements associated with data use to support the business processes.

The amount of work required by asset owners to ensure continuity of data modeling and exchange across the various lifecycle enterprise software systems and to organize collaboration between internal and external stakeholders is not trivial. Considering this, despite increasing documentation of the benefits of BIM adoption (e.g., as documented in European Union's BIM handbook), it is understandable that progress related to lifecycle BIM implementation among public highway infrastructure owners has been slow in the U.S. compared with other sectors (e.g., buildings) which have had decades of head start. This is not to say that no progress has been made at all in the highway sector. Certainly, within certain phases of project delivery, notably in major projects, the U.S. is a leader in the use of 3D engineered modeling. 3D

[1] It is important to note that the term "data modeling" used in this report refers to both conceptual information modeling to structure information and modeling of geometry-objects and abstract objects (as it is done in road projects with computer-aided design or CAD-software. BIM-mature agencies place emphasis on conceptual modeling to define structured information, which is then used in CAD-software/software in general.

modeling has enabled collaborative BIM workflows and deliverables to support both integrated design and construction (e.g., automated machine guidance and construction schedule integration). However, more work is needed to fully realize the promised information management benefits of BIM across the entire lifecycle.

Global Benchmarking Study Objective

This study was conducted on behalf of FHWA's Global Benchmarking Program (GBP), which serves as a tool for accessing, evaluating, and implementing proven foreign innovations that can help improve highway transportation in the U.S. The purpose of the study was to document evolving trends in BIM implementations in BIM-mature nations and their public highway infrastructure agencies, with a focus on understanding how other countries are using BIM for infrastructure to better deliver transportation projects, manage assets, and provide related services with a view to benchmark and advance U.S. practice. The study was conducted in two parts: (1) an initial desk review to document the international state of the practice and identify target countries; and (2) a follow-on study tour that included visits to BIM-mature agencies in the United Kingdom, the Netherlands, and Norway to discuss and examine core aspects of BIM for infrastructure implementation in greater depth. This report specifically documents the study tour portion of the study.

This study is set against a backdrop of steady and growing use of innovative digital technologies to design and construct capital highway projects or to monitor their condition and performance. Examples include use of 3D engineered models, automated machine guidance, e-Construction methods, light detection and ranging (LIDAR) scanning, and unmanned aerial systems. Through its research and development and innovative technology deployment efforts, Federal Highway Administration (FHWA) has led efforts to foster greater use of digital work processes, tools and technologies with the goal of improving safety, quality, and productivity of highway project and service delivery. These efforts, when taken in totality, represent some of the necessary pre-conditions for BIM to take root and prosper. Similarly, in October 2019, AASHTO passed a resolution to adopt the Industry Foundation Classes (IFC) schema developed by buildingSMART International as the standard data schema for exchanging electronic engineering data in an interoperable manner across asset life-cycle phases for the bridge and road infrastructure disciplines—a significant nod to BIM-based work methods. Several State Departments of Transportation (DOTs), both individually and as part of a bridge pooled fund effort, are also advancing their own BIM initiatives in this regard.

Observations and Lessons Learned from the Global Benchmarking Study

This study holds many lessons for the U.S. transportation industry to accelerate their BIM-related efforts. The BIM development efforts of the studied agencies demonstrated clear motivation, purpose, goals, and top-line support, which recognize both the costs, and more importantly, the benefits of adopting BIM for infrastructure. The officials visited offered the study team invaluable advice related to priority activities to focus on and key international efforts to follow in this fast-developing field. The BIM for infrastructure practices they developed applied to varied populations, topographies, and geographies that exist across the international landscape, from the United Kingdom to the Netherlands and the Nordic countries (Denmark, Sweden, Finland, Norway). Despite the diversity of settings, the study team found that these countries have achieved a high level of BIM for infrastructure maturity through implementation of five universal components, or steps. They include:

1. Governmental recognition of the importance of BIM to the infrastructure sector (on a national and European level) backed up by agency leadership support are critical success factors.
2. Public infrastructure asset owners hold the keys to stimulate industry action to embrace open BIM practices. These owners could organize at the national level and, preferably across sectors, to (1) ensure that the right legal, institutional and technological conditions exist for digital information procurement and delivery; (2) drive the development and adoption of open and interoperable data modeling and exchange standards; (3) exert influence on the information technology (IT) providers to ensure availability of tools to support information exchanges; (4) prepare a skilled workforce; (5) incentivize implementation of BIM principles, policies, processes, standards, tools, and technologies in project delivery and operations and maintenance.
3. The development and execution of a multi-year strategic plan that articulates BIM for infrastructure targets/goals and logically sequences the essential work needed to advance BIM for infrastructure maturity gives direction and guides work.
4. Collaborations with industry partners nationally and standards organizations internationally help promote wider acceptance of BIM-related policies and avoid duplication of effort.
5. Long-term sustenance of BIM efforts can be ensured by connecting it to broader policies and digitalization efforts related to value from public data, data governance, and data modeling and linking/integration across various information modeling domains, e.g., geographic information system (GIS).

The study team delved into each of these aspects of BIM implementation and identified the following:

- Key observations and lessons that need to be learned from the countries visited.
- Recommendations for leaders and practitioners based on the observations and lessons.
- Implementation tactics (strategy) to execute the recommended actions.

Key Observations and Lessons

The following is a thematically arranged compilation of key observations made by the study team:

BIM Awareness, Leadership, Preparation, and Collaboration

- **A shared national vision or regulation is key to moving the ball.**
    - BIM-mature agencies focus on two critical success factors: widespread BIM awareness and collaboration with various sectors, infrastructure project and services delivery partners and international agencies.

  - A national BIM roadmap is a useful starting place. It is important to be ambitious in setting the vision, e.g., require the model as a contract document, and establish organizational and asset information requirements, etc.
  - Leadership support is critical at all levels of deployment and implementation—national, DOT, DOT unit, and practitioner level. The key is to have a shared national vision and use that to deploy dedicated BIM programs. While highway transportation agencies in the Netherlands, Finland, and Norway have created BIM programs to fuel enterprise-wide BIM development, deployment, and training, the agencies in Sweden and Denmark are capitalizing on opportunities to pilot BIM on major projects even without a dedicated enterprise-wide BIM program.
  - In the UK, the "so called" UK BIM mandate[2] helped drive things through the organization—it got things started.

- **BIM is as much about cultural shift and change management as it is about technology and tools**.

  - Leadership is key to driving change; find someone with power and position or with the ability to drive change within the organization through innovative thinking, new ideas, and methods. Leadership does not have to come from position. In fact, people in positions to make decisions often need to be convinced and guided to make the right decisions through ground-up "proofs of concepts."
  - The focus of the leadership should be on the benefits, and on the risks from not adopting BIM. To create buy-in, create benefit streams/incentive for each stakeholder from implementing BIM processes. The question to address is not "why should we implement BIM?" but rather, "why not BIM"?
  - Home in on the opportunities to create momentum in the spirit of "never let a good crisis go to waste." Big challenges can be the source of big changes.

- **Client Organization (e.g., DOTs in the U.S.) action is crucial**

  - Public client information requirements and process re-engineering around data delivery and use are recognized as an essential starting step to catalyze action within the organization and within the consultant, contractor, and software vendor communities.
  - Embracing open standards by client organizations signals that collaborative work is needed from national and multinational supply chain actors in the private sector.

  - Public clients from multiple sectors collaborate to advance BIM (e.g., roads, rail, water, buildings). Participation of the public clients in industry BIM forums provides opportunities for collaboration.

[2] Organizers of the UK leg of the study tour and their guests were quick to point out that the "UK mandate" was not necessarily a hard mandate. It was a soft mandate in that there were no penalties associated with non-implementations. It catalyzed action and allowed agencies interested in implementing BIM practices to engage with their stakeholders and do so.

- In the procurement strategies of public clients, the creation of a "level playing field" for every market party is key. Investments in open standards in order to prevent "vendor lock in" and secure interoperability across software systems help accomplish this goal.

Building Blocks of BIM for Infrastructure: Organizational Structure, Data Modeling, Data Exchange, and Management Platforms

- **Organizational Structure, Roles and Responsibilities**
  - BIM roles such as BIM Coordinator, Data Owners, Data Stewards, etc., are defined at the organization and/or project level.
  - Responsibilities are associated with each BIM role to cover all aspects related to BIM data management, be it: modeling, data quality, data integration, model reviews, etc.
  - Organizational and project structure incorporates BIM roles and responsibilities.
  - BIM in projects plus simultaneous development of tooling, standards, and/or systems require a cooperative relationship between client and contractor above and beyond strict contractual relationship defined on paper. This is to maximize the usage of the knowledge, ideas, and capacity to solve the joint problem of successful BIM implementation.
- **BIM for Asset Owners is all about data and information management**
  - People may not or do not need to know the definition of BIM; focus needs to be on what outputs of BIM are for each stakeholder and not the term. Because the term BIM has historically meant different things to different stakeholders, which takes away from its meaning as perceived today, a core message was to de-emphasize the acronym BIM and not to be boxed in by the term BIM. Drop the "B" in BIM because at its heart, BIM is about data and information management to generate institutional knowledge from the data and information flows to support decisions.
  - BIM is not about Management Information Systems (MIS). The start point for BIM is not through MIS rather it tracks the life cycle of data from its point of origin, e.g., design information models. BIM does not equal design or 3D models but they are a logical starting point to organize information. The interest is in assets and asset-related information and aggregate information from various sources to be able to decide on proper planning for (re)construction and maintenance. It is important to start with the life cycle (i.e., assets and asset network information) in mind.
  - BIM is about open and shareable data and information management across asset life-cycle phases. Interoperability of data is being seen as key to avoid vendor and system "lock-in" and to ensure that data is FAIR (Findable, Accessible, Interoperable, Reusable) across platforms, tools and data systems, irrespective of the format that was used to create it. The focus should be on getting access to all the information when needed rather than a part of it.
  - International agencies are looking to adopt multiple object-type library (OTL) standards to support all asset life-cycle phases. Two aspects are associated with adopting multiple OTLs and establishing standards for data modeling. The first involves adoption of one or more foundational open standards that establish the base objects, relationships, and properties at a

generic level. For example, for the design and construction phase and for the information handoff to asset management, IFC and its derivatives (e.g., ifcOWL) are emerging as the preferred standard. Other data modeling standards that are emerging include Open Geospatial Consortium (OGC) standards like InfraGML and CityGML. The use and application of graph data modeling standards such as Resource Description Framework (RDF) and its derivatives (e.g., RDF-a) are also being pursued. The second involves detailed definition of the object properties for each of the objects adopted from the open standards, depending on the business requirements. This involves standardizing OTLs by taking the OTLs from individual government agencies and business functions that operate with the country and developing standards across them. For example, in Norway, all government agencies that survey/register/change geodata manage their own data models with varying quality and detail.[3] Centralized definitions of object properties have been developed at both the national level (Norway's Vegkart[4] and OTLs by discipline[5]) and the international level (INSPIRE[6]) to establish a common basis to all information about objects in an OTL. In Norway, there is a great emphasis on using GIS information modeling as a basis to link 3D modeling information from the project delivery phase and other maintenance information from the O&M phase.

- International and European standardization in the field of BIM is carried out in the ISO TC59/SC13 and CEN TC442 committees. IFC standards established in buildingSMART International have been recently adopted by ISO and CEN.
- Currently the focus is on project delivery phases (planning, survey, design, and construction), but eventually agencies aim to extend the use of data and information management standards and techniques to built asset operations and maintenance related business functions.

[3] Norway Data Models. https://www.kartverket.no/geodataarb[eid/standardisering/sosi-standarder2/sosi-del-2-generell-objektkatalog.
[4] Norway Asset Information Database (NVDB), Vegkart. www.vegkart.no
[5] Norway Data Models Organized by Disciplines. www.geonorge.no
[6] INSPIRE. https://inspire.ec.europa.eu/

1. Introduction

1.1 Background

Once considered just for buildings, Building Information Modeling (BIM) is gaining rapid acceptance in several infrastructure industries, including highway transportation. BIM, as applied to highway infrastructure (referred to in this report as BIM for infrastructure), involves delivering capital projects collaboratively (through the planning, design, and construction phases) and managing services the built infrastructure is expected to provide efficiently using digital processes rather than traditional paper-based processes. At its core, BIM is about collaboration around data and information related to assets and asset networks across their life cycles using open standards. By aligning data within and across an agency's information systems in a manner that allows them to be managed easily, "open BIM" has the potential to break down information silos and offer major productivity gains and cost efficiencies for implementing Departments of Transportation (DOTs) across all life-cycle phases of built infrastructure.

By one estimate, the financial opportunity of digitalizing engineering, construction, and operations processes for roadway and bridge projects using "open BIM" is in the range of 16 percent savings on total capital project expenditure.[7] One European Union report[8] notes that from 2020 onward, the estimated yearly cost savings from using BIM processes in the design and construction phases alone, as a percentage of the total construction budgets in five European Union countries (the Netherlands, Sweden, Finland, Norway, and the United Kingdom [UK]), varies between 5 and 20 percent (at an average of 8.2 percent).

The movement toward BIM for infrastructure has been growing in the United States (U.S.) and is becoming more widely used by industry, including engineers, planners, contractors, and owners. Several Federal agencies (e.g., the U.S. Army Corps of Engineers, the General Services Administration) now encourage the use of BIM to drive efficiency and cut waste. The Moving Ahead for Progress in the 21st Century Act MAP-21 (MAP 21) provides incentives for projects that use advanced technologies such as three-dimensional (3D) engineered models—which are content-rich, BIM information models developed in the design phase of project delivery. In addition, the Federal Highway Administration's (FHWA) Every Day Counts (EDC) initiatives have encouraged digital innovations such as geospatial collaboration, intelligent compaction, e-construction, digital as-builts, and e-ticketing—tools and technologies that support BIM processes.

Despite these developments, progress related to BIM implementation in the highway infrastructure arena has been slow in the U.S. compared to other industries (e.g., buildings). In many ways, this is in line with what other nations have found. This is because highway projects involve significant complexity in which

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[7] Jones, S.A. and D. Laquidara-Carr, "The Business Value of BIM for Infrastructure 2017," Dodge Data Analytics, 2017.
[8] Meerkerk, J. and B. Koehorst, "Utilizing BIM in National Road Authorities," Conference of European Directors of Roads, April 2017. https://www.cedr.eu/download/Publications/2017/Utilising-BIM-for-NRAs-TR2017-05.pdf (last accessed: February 27, 2019).

information about the project site (nature, geology, terrain, etc.), machine control, the Global Navigation Satellite System (GNSS), LIDAR, terrain modeling, mass balance, network navigation, etc., needs to be standardized in addition to specific roadway objects that are being built. The overarching challenges to advancing BIM and achieving the full benefits from its use for infrastructure are identifying the needs of each life-cycle phase and standardization of the data to be exchanged and interoperability of the data across various phases. Several countries around the world are further along in advancing BIM for infrastructure and are developing a common set of standards and partaking in international consensus efforts to address the interoperability challenges. Many of these countries claim significant benefits from implementing BIM for infrastructure processes within their highway agencies. Engaging these countries and learning from their experience will allow FHWA and its partners to rapidly advance the deployment of BIM for infrastructure in the United States and help ensure U.S. standards, specifications, and systems leverage successes, learn from failures, and are consistent with those being developed and used internationally.

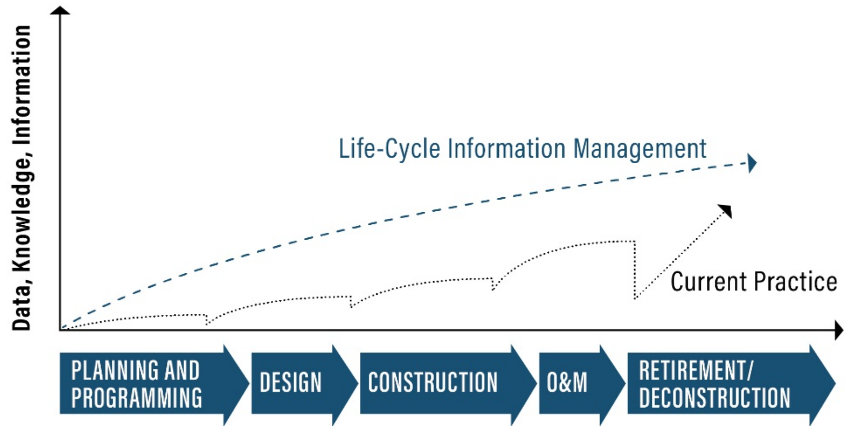
1.2 Objective of the BIM for Infrastructure Global Benchmarking Study

This study was undertaken under FHWA's Global Benchmarking Program (GBP), which serves as a tool for accessing, evaluating, and implementing proven foreign innovations that can help improve highway transportation in the U.S. The objective of this study is to document how other countries use BIM for infrastructure to better deliver transportation projects, manage assets, and provide related services throughout their life cycles. Specifically, it documents noteworthy BIM practices and translatable lessons learned from these countries and benefits realized by them. The study was conducted in two parts: (1) an initial desk review; and (2) a follow-on study tour that included visits to BIM-mature agencies in select countries to discuss and examine core aspects of BIM for infrastructure implementation in greater depth. This report specifically documents the study tour portion of the study.

This GBP study is intended to better inform FHWA's efforts to facilitate wider use of BIM for transportation infrastructure projects. FHWA goals that have driven this study are: (1) to accelerate infrastructure project and service delivery by advancing the use of BIM; and (2) help the U.S. highway industry better compete in the global arena where BIM is gaining rapid acceptance. BIM for infrastructure directly supports U.S. regulatory requirements, including the requirements on data-driven and performance-based approaches to asset management outlined in Title 23 of the United States Code (23 Code of Federal Regulations [CFR] § 515.9, 23 CFR §144 (a)(2), 23 CFR § 150, and 23 CFR § 106(j)) and the FHWA's national strategic goals on infrastructure and innovation.

1.3 Study Context: BIM for Infrastructure and its Promised Value

Despite the pervasive and ever-growing use of digital tools, processes, and technology within the highway sector, information exchanges regarding built assets across their life-cycle phases (including planning and programming, design, construction, and operations and maintenance [O&M]) are still largely paper-based or document-centric. Even when electronic documents are exchanged, they largely emulate paper and cannot be used to easily harvest data or information contained in them. This prevailing practice results in information losses within and between asset life-cycle phases (see figure 1-1) leading to a waste of resources to recollect information or making decisions using incomplete information. With its emphasis on collaborative organization of data and information management across life-cycle phases, BIM for infrastructure offers an opportunity to minimize information loss, breakdown information silos, and create greater levels of data integration. This, in turn, drives greater efficiency and productivity gains and solid whole life-cycle decision making.



Source: After Borrmann et al. 2018 and Crossrail Limited 2013.

Figure 1-1. Chart. Current practice versus ideal life-cycle information management.

BIM for infrastructure offers benefits for all stakeholders involved in highway transportation, including public owners; e.g., State DOTs, private sector participants, and society at large. For public owners, the expected benefits include:

- Direct cost savings—ability to do more with less, e.g., ability to stretch capital program dollars further as in being able to build “5 bridges for the price of 4” and addressing the significant deferred infrastructure upgrade needs in the U.S.
- Responsible use of financial and natural resources.
- Improved output quality of public built assets and related services.
- Greater transparency and collaboration with the construction and service sector partners.

By boosting the performance of the highway construction sector, BIM for infrastructure offers a ready-made alignment opportunity with government-wide digital policy initiatives aimed at stimulating economic growth.

1.4 Study Methodology

1.4.1 Selection of Countries for Study Team Visits

As stated earlier, the desk review preceding the study tour was used as a first-cut basis for selecting the countries and agencies to visit. The desk review assessed the maturity of BIM practices in several countries using key criteria. The countries investigated were France, Germany, South Korea, the Netherlands, Norway, Singapore, and the UK—all widely regarded to have strong and emerging BIM practices. Table 1-1 provides a comparative view of how each country fared against the criteria investigated. Check marks in the table represent a positive overall rating of country against the specific criterion assessed, while Xs indicate a negative overall indication. Three specific criteria could not be assessed from the desk review because of a lack of published information (the last three rows in table 1-1). Assessment of BIM-maturity along these criteria was made a part of the in-person assessments during the study tour.

The population estimates of each of the countries investigated are listed in table 1-1 for comparability with typical populations of U.S. States/territories. For reference, in 2019, the U.S. population was approximately 328 million—the largest State (California) had a population of 40 million, the median State (Louisiana) had a population of 6 million, and the smallest State (Wyoming) had a population of 0.6 million.

Table 1-1. Comparative assessment of BIM maturity of various countries across preset criteria from the BIM GBP desk review.

Criteria	France	Germany	South Korea	Netherlands	Norway	Singapore	United Kingdom
Population (millions)	67	83	51	17	5	6	66
Leadership							
Has a countrywide BIM roadmap been developed and published?	✓	✓	X	X	X	✓	✓
Framework							
Are BIM deliverables required or incentivized for publicly funded construction projects?	X	X	X	✓	X	X	✓
Do requirements specify providing native BIM files of specific software?	✓	✓	X	✓	✓	✓	✓
Do requirements specify non-proprietary data formats?	✓	✓	✓	✓	✓	✓	✓
Do requirements allow for specific information requirements to be specified for defined client use?	X	X	✓	✓	✓	X	✓

Criteria	France	Germany	South Korea	Netherlands	Norway	Singapore	United Kingdom
Are required attributes based on authoritative sources proven with broad engagement?	X	✓	X	✓	✓	X	✓
Do requirements specify content specific for infrastructure projects?	X	✓	✓	✓	✓	X	✓
Communication							
Are requirements presented in a form that is approachable and understandable to users?	X	X	X	✓	✓	X	X
What efforts have been made to communicate with BIM software vendors?	X	X	X	✓	✓	✓	✓
How have software vendors responded to supporting requirements?	X	X	X	✓	✓	✓	✓
What communication has been established with contractors submitting information?	X	X	X	✓	✓	✓	✓
How have contractors responded to submitting required information?	Could not be assessed.						
Implementation							
Are contractors providing content that is required by agencies? Yes	Could not be assessed.						
Are agencies using the content that is provided by contractors? Yes and No	Could not be assessed.						

Based on table 1-1, the Netherlands, Norway, and the UK stood out for their BIM practice maturity. Given their geographic proximity, these countries were chosen for on-site visits to examine their BIM practices in greater depth. As the planning for the study tour was underway, the FHWA organizers became aware of an opportunity to meet representatives of multiple Nordic countries, including Denmark, Finland, and Sweden, along with buildingSMART International's Nordic chapter representatives, while in Norway. Members of the study team were already aware of the maturity of BIM practices within these agencies; therefore, they decided to meet with representatives from all these countries, including Norway, as a group during the Norway visit. Table 1-2 presents the countries visited and agencies interviewed during the study tour.

Table 1-2. Countries and agencies interviewed as part of the BIM GBP study tour.

Country	Agency Interviewed
The Netherlands	Rijkswaterstaat (RWS)
Norway	Norwegian Public Roads Administration (NPRA) and Bane NOR—Norwegian Railway Infrastructure Managers
	Danish Road Directorate (DRD)
	Finnish Transport Infrastructure Agency (FTIA)
	The Swedish Transport Administration (Trafikverket) (Sweden)
United Kingdom	Center for Digital Built Britain, and representatives from several other agencies including: • The Department for Business, Energy and Industrial Strategy • Environment Agency • Consulting industry and other private sector entities

1.4.2 Areas of Focus During the Study Team Interviews

The European Union BIM Task Group uses four "pillars" to categorize BIM initiatives. The study team focused on these pillars in obtaining information related to BIM for infrastructure during the in-person interviews.

- **Leadership**
  - Compelling drivers, visions, and goals.
  - Aligned value proposition and strategy.

- **Framework**
  - Policy (legal and contractual, procurement, specified data requirements, and execution plan).
  - Technical (security, technical information, validation, and use).
  - Process (standards for data and information exchange, collaborative working and coordination, and information management).
  - People (responsibilities, skills, capacity, and incentives).

- **Communication**
  - Engagement with industry stakeholders.

- **Implementation**
  - Early wins, pilot projects, and training.
  - Lessons learned.

In conducting the in-person interviews, the study team placed special emphasis on some key areas within these broader categories where published literature is deficient—data and standards used to populate and guide the development of "information models," tools and technologies used to build information models, and specific implementations in the highways sector.

Appendix A provides a more comprehensive list of the amplifying questions that the study team used during the interviews. It is noted at the outset that because of the short nature of the trip, it was not always possible to obtain in-depth information on any given technical aspect or even a uniform coverage of information across a given topic among the various host countries. Further, given the diverse domains within which BIM is being practiced within the host countries outside transportation infrastructure (e.g., rail infrastructure, water), it was challenging to elicit focused information regarding highways. This situation was most acute when the study team was in the UK, where discussions around BIM were more broad ranging and not specific to highways. To make up for the lack of uniformity and specificity of the information collected, the study team performed additional outreach, to the extent feasible, to the host agency points of contact after the tour was completed. Therefore, the information presented is a combination of the information gathered when on-site as well as information received after the study tour was completed.

1.5 Study Team Composition

The study team comprised a diverse group of practitioners and researchers who are well versed in BIM for infrastructure issues in the United States:

- **Connie Yew, P.E.,** Team Leader for Construction Management, FHWA Office of Infrastructure.
- **Katherine Petros,** Team Leader for Infrastructure Analysis and Construction, FHWA.
- **April Blackburn,** Acting Assistant Secretary of Finance and Administration and Chief of Transportation Technology, Florida Department of Transportation.
- **Michael J. Kennerly, P.E.,** Director of the Office of Design, Iowa Department of Transportation.
- **Roger Grant,** Executive Director, Building Information Management, National Institute of Building Sciences.
- **Jagannath Mallela, Ph.D.,** Senior Vice President and Director of Research and Innovation Solutions, WSP USA Inc. (Study Report Facilitator).

Appendix B presents short biographies of the members of the study team.

1.6 Report Organization

This report is organized into the following chapters:

Chapter 2 presents an overview of issues related to awareness, leadership, preparation, and collaboration around BIM at each of the host agencies interviewed. The chapter concludes with an assessment of the BIM maturity of each host agency against a set of factors deemed critical to the adoption of BIM and its sustainability. The maturity assessment was made strictly as an interpretation of the study team's understanding of the BIM practices based on the on-site interviews conducted and post-interview documentation review. None of the host agencies was asked to participate or provide input into the maturity assessment; however, they were allowed an opportunity to review the information presented.

Chapter 3 is a more technical chapter that outlines the effort each agency is undertaking to build strong foundations for BIM to establish it as a mainstream business approach. This includes an overview of how agencies have formalized data and information requirements, classified assets, defined structured and organized representations of information about built assets (i.e., “object-oriented” representations), and implemented BIM processes to ensure a supply of data and its use during asset life-cycle planning, design, construction, and O&M. This chapter is for a technically minded reader in an infrastructure discipline (e.g., roads/bridges, highway design, construction, asset management) or an information technology (IT) specialist at an agency who is involved with BIM initiatives.

Chapter 4 illustrates how BIM for infrastructure processes, tools, and technologies are being implemented at the various agencies through pilot or “real-world” projects. This section also discusses where BIM professionals and functions fit within the organizational structure of BIM-mature enterprises.

Chapter 5 identifies key findings from the study tour and, using this as a basis, proposes recommendations for BIM implementation in the United States.

2. Awareness, Leadership, Preparation, and Collaboration Around BIM at Host Agencies

CHAPTER SUMMARY

- Most host organizations recognized BIM as a means to improve information management in an open, shareable manner across the life cycle of built assets. This means integrating data from models in design with other project life-cycle management data managed in construction, asset management, using GIS as a solid data modeling and linking foundation.
- BIM is generally supported by a national government mandate in most host organizations visited. However, it is not always funded at the national level.
- Leadership and funding at the road authority level is more common and is an essential first step to kick start the process for preparing for open BIM.
- The current state-of-the-practice indicates that most agencies are advancing BIM through their activities in the project delivery phase as a first step—most notably information exchanges between the design and construction phase. Many of the current BIM pilot and project efforts are major capital projects where there are resources (both human and financial) available to try an innovative approach like BIM.
- Common challenges to implementation appear to be the amount of effort required to bring about organization cultural change, ensure technical competence within the owner organization, as well as industry outreach and cooperation. This amounts to roughly 50 percent of the effort whereas the remaining effort is in tackling the foundational technical work required to enable BIM.
- Establishing information requirements, developing information exchange standards, providing a legal/contractual basis to enable digital information exchanges between market parties, and adopting an information classification basis for infrastructure and the associated data structures are all a part of the technical work that needs to be done to establish a wider BIM foundation.
- Most agencies visited on the study tour suggested working collaboratively with multiple stakeholders both within transportation (e.g., rail, transit) and outside (e.g., buildings, water) nationally and internationally to address the building blocks. Key lessons learned that are applicable to the U.S. efforts in BIM are (1) to create a national coalition first with other public sector partners and private industry to seek "buy in," exchange knowledge and build capacity; (2) leverage international BIM efforts related to standards development, research and other technical work to avoid "reinventing the wheel"; and (3) extend or adapt international standards to support national demands (e.g., regulations) and needs.
- Mature BIM organizations that are spending the time and energy necessary to restructure data and information modeling practices to break down data "silos," promote data interoperability, and automate work tasks. This work is deliberate and time consuming but is considered an essential task.

2.1 Introduction

Inertial responses to change among individuals and within agencies are common and must be anticipated when confronted with disruptive change of the scale BIM for infrastructure heralds. The adoption of BIM for infrastructure requires openness to new ideas, agencywide, and discipline-specific receptivity and commitment to change, a well-thought-out change management process, and close collaboration with all relevant stakeholder groups. **As the primary beneficiaries of open BIM for infrastructure practices, public infrastructure owners and operators are in the unique position of making the change happen.** Leadership at these agencies must be convinced that the change is rooted in a solid business case in terms of its strategic alignment with the agency's vision, goals, and objectives; brings economic benefits to the society at large; can be funded sustainably; and can be implemented with success. BIM champions at agencies must be prepared to make the business case and assist with the delivery of the change.

The global benchmarking study recorded host agency perspectives on aspects of leadership actions and agency activities that led to their current advanced states of BIM maturity. The study team then conducted additional outreach with some of these agencies to obtain and research documents mentioned in the interviews to understand better the key issues recorded during on-site interviews. Highlights of the information gathered through this process are presented in this chapter.

2.1.1 Critical Success Factors as an Organizing Theme to Document Study Findings

The information regarding various host agency BIM practices presented in this report is organized and presented consistently across various categories of interest to the benchmarking exercise. The categories chosen for presentation are essentially what the study team deemed as critical factors for successfully mainstreaming BIM. These critical success factors were drawn from the capability maturity framework (CMF) presented in NCHRP Report 750 Volume 7 (Mallela et al., 2019) to organize an agency's readiness to embrace emerging practices or innovations.

Table 2-1 presents the critical success factors used to assess a given host agency's actions and the components of assessment within each factor. Following the methodology outlined in NCHRP Report 750, Volume 7, agency capability was subjectively assessed at three levels—1, 2, and 3. The general characterizations of the levels are as follows:

- **Level 1**: The agency is in a relatively weak position to advance BIM for infrastructure with significant gaps in capability.
- **Level 2**: The agency is in a potentially tenable position to advance BIM for infrastructure but should address some gaps in capability that could pose risks to a successful implementation.
- **Level 3**: The agency is well positioned to advance BIM for infrastructure.

Table 2-1. Critical success factors and components assessed to measure BIM maturity in host organizations.

Critical Success Factor	Components
A. BIM Awareness and Leadership Support	○ Top-down support ○ Leading edge practices ○ Status of research and development (R&D) in progress ○ Problems being addressed
B. Performance Awareness and Application	○ Alignment with agency performance goals ○ Performance measures ○ Assessment of anticipated benefits and costs ○ Challenges and risks
C. Supportive Systems and Staff to Enable BIM for infrastructure	○ Agency pilot testing ○ Institutional knowledge management ○ Staff capacity ○ Access to funding
D. External Collaboration	○ Interaction with transportation agency and academic peers ○ Communication beyond the transportation community ○ Private sector outsourcing and partnering

2.1.2 Definition of BIM Among Host Agencies

The acronym BIM has been interpreted and expanded differently by various authors and institutions over time. It has been used as a digital representation of a physical asset or a "digital twin" by some (as in Building Information Model). Others have described it as the process of working collaboratively in building projects with the aid of digital information models (as in Building Information Modeling). Others hold an even more expansive view that BIM is a way of structuring, managing, and using or reusing digital building information throughout the entire life cycle of an asset (as in Building Information Management).

As the definition of the term BIM evolved, so did its areas of application. For some, BIM is synonymous with 3D-engineered model-based information exchanges in the design phase. For others, BIM covers the entire project delivery phase to include project planning, design, and construction. Many consider the definition of BIM to be even broader and applicable to data and information exchanged across all project life-cycle stages to include information related to both physical assets and asset networks as well their use (e.g., real-time traffic, condition, performance).

An interview participant from the Dutch ***Rijkswaterstaat (RWS)*** indicated that BIM is about "making actionable information as readily available as possible." For RWS, BIM supports its mission by making actionable information about its highly codependent infrastructure and waterways assets and infrastructure networks as readily available as possible. RWS embraces all definitions of BIM and interprets them in the broadest sense of the term—Building Information Management. Participants referred to this as the "big BIM" view during the discussions.

However, RWS also understands that "little BIM" activities (i.e., BIM-aligned activities within the design and construction life-cycle stages) are essential stepping-stones to achieving the "big BIM" vision. For RWS, infrastructure is approached from an asset information management perspective where the agency's main mission is to maintain the infrastructure assets and the networks (including the water networks) in good shape using the best available asset and operational information. Design and construction are viewed primarily as disruptions to this mission. This perspective underpins RWS' definition of BIM. RWS participants noted that it took some convincing at the political level to cement this perspective and that the organization is making incremental progress to becoming data-centric.

RWS considers data to be a vital asset of the network of roads, waterways, and ecosystems. Besides the ownership of the physical network, the digital representation of it equals the importance of the physical one. Without a good quality digital representation, the value of the network is only part of what it could be with a solid digital representation. This was a key conclusion of the board of directors of RWS from the 2012-2017 period. This conclusion was the driving force to continue with the RWS AIRBIM program for a second phase.

In the ***UK***, there is growing realization that BIM should stand for "Better Information Management." A participant from the UK BIM program advocated that the current shift is to move away from the term BIM. The Centre for Digital Built Britain (CDBB) now refers increasingly to the broader term Information Management instead of the narrower term, BIM. According to a representative from Department of Business, Energy & Industrial Strategy (BEIS), defining the term BIM accurately was less important than articulating to the construction supply chain, in a consistent and unambiguous manner, "*what information to deliver, how to deliver it and when to deliver it*" across an asset's life cycle. This representative opined that there are many people in the construction supply chain who would use the outputs of BIM but would never need to know what it stands for. Similarly, in Norway, NPRA avoids the use of the term BIM in their regulations since it seems to confuse the discussion. They emphasize defining deliverables that have a clear definition.

Although no structured discussions were held with representatives from the ***Nordic*** highway organizations (including those from DRD, FTIA, NPRA, and Trafikverket) around the topic of BIM, informal discussions revealed these organizations were opting for the broader, "big BIM" definition of BIM. These organizations view BIM as way to manage data and information flow better through the infrastructure project life cycle, including georeferenced basis data, planning, design, construction, and asset management. For them, BIM-related information exchanges are based on open standards and model-based work processes for better quality, communication, and management of data and information. They expressed that BIM is an enabler to "liberate data" from silos and avoid "vendor lock-in." They emphasized that to achieve the benefits of BIM related to data and information flows, agencies must organize or classify information using a set of rules as a precursor. Chapter 3 discusses how the Nordic organizations and RWS have made great strides in this regard.

2.2 Awareness of BIM for Infrastructure and Leadership Support

The study team assessed awareness in terms of the agency's understanding of what BIM for infrastructure is, what it does, where it should work well, where it might not apply, and the level of effort and resources required to advance its full-scale implementation (staffing, expertise, tools, technologies, time, and budget). Awareness was also assessed in terms of how in tune the agency is with the state-of-the-art, national, and international trends in BIM, and where it fits within this context. Research and development in progress and problems being addressed were also used as measures of awareness.

The Netherlands/RWS

BIM Context Awareness: RWS is a part of the Dutch Ministry of Infrastructure and Waterways and is responsible for managing highways, waterways, and water systems (water quality and water quantity (flood control)). Traditionally the interdependence of all infrastructure facilities and waterways drove a culture of collaboration among various public client organizations. In the infrastructure arena, digitalization using BIM is seen as an extension of that story. RWS does not perform in-house design or construction. It mainly relies on information that comes from design-construction contractors to maintain and manage its assets. In this context, having access to high quality and reliable information that BIM for infrastructure offers, is of vital importance to asset management.

RWS' Primary Motivations

- FAIR data
- To create a digital representation of the network that equals at least the physical one
- Information delivery for and during asset management
- Part of a larger government goal to digitalize economy but with no binding BIM mandate

Starting in 2012, executive leadership within RWS funded a BIM program and focused it on major projects to improve the reliability of data. An implementation plan to mature BIM for infrastructure practices is ongoing. This program focused on open BIM standards initially to exchange data about built assets among client organizations/system operators, construction contractors, and maintenance contractors. The apparent success of this program led to the Area Information Rijkswaterstaat 2020 (AIR2020) program started in 2016, which aimed to achieve a single integrated information system for data pertaining to a geographical area. At the beginning of 2019, RWS decided to launch the AIRBIM program to align asset management systems with design and construction systems using special data modeling techniques called object-oriented techniques. RWS established a special chief data officer position to assist with its organization-wide information needs.

Current Efforts: With the available funding, RWS advances its BIM program in four areas of parallel development listed below (in decreasing order of priority).

- Controlled development and phases of implementation for the new products and services.
- Improving and standardizing the use of the existing process and applications.
- Organizational change management, importance of collaboration to achieve consistent data.
- Benefit monitoring and investment in (inter)national development of standards.

FTIA's Primary Motivations

- ❖ Economic opportunity and improve data exchange between "silos"
- ❖ Supported by a government mandate
- ❖ Strong alliance with construction supply chain and software industry

RWS is aware of some of the key challenges with BIM implementation across all jurisdictions (regions) under its control—a significant factor is the alignment of IT systems at the regional level and the central office. Another potentially greater challenge is in managing organizational change. RWS is working to address both these challenges.

Leading-edge Practices: RWS is at the leading edge of open BIM R&D efforts. It has completed several data standardization initiatives for infrastructure specific to the Netherlands that may be useful for other countries/organizations, including (1) a standard for communication and the process of exchange of information in construction projects (VISI); (2) an unambiguous description of physical and spatial built environment concepts used in the RWS-managed road networks (Road Object Type Library or OTL); (3) a way of organizing project data from various deliverables that may be interlinked (COINS: a Dutch open standard for data exchange packaged in a container being able to use OTLs, now published as ISO 21597 parts 1 and 2); (4) a novel data modeling and linking framework to share data across BIM tools; and (5) GIS tools (linked data concept). Within the Netherlands, RWS routinely collaborates with several stakeholders and throughout Europe to champion R&D and standardization efforts.

The first phase, 2012-2017, was evaluated by the national office for governmental IT development. The main conclusions were:

- Modernize the asset management system (AMS): a huge effort;
- Align the OTL, COINS, and AMS and simplify and modularize;
- Continue the good work in a second phase!

Finland/FTIA

BIM Context Awareness: The responsibility for infrastructure at the national level is delegated to the Ministry of Transport and Communications and there to the Finnish Transport Infrastructure Agency (FTIA). FTIA is responsible for national roadways, railways, and waterways. It manages an annual budget of €1.6 billion and employs 400 permanent personnel. In 2007, Senate Properties of Finland, a part of the Finnish Ministry of Finance, required the use of BIM processes on national publicly owned (building) projects to improve project management. A Finnish government sponsored project called RASTI, aimed at standardizing information management in the built environment, estimates that by 2030, savings from better information management to reach €300 million and the impact on productivity associated with digitalization to be in several billion euros per year. Risk and safety issues were flagged as a major concern. These concerns were the backdrop for advocating for better use of advanced information and communications technologies (ICT) across the government to digitalize various sectors of the economy. In 2012, Finland developed the "Common National Requirements for Building Information Modeling (coBIM)" to specify a standard way to carry out building projects using BIM methods. However, it was only in 2015, that FTIA expanded coBIM for the infrastructure industry to include highways, railroads, and waterways. FTIA has been committed to open BIM as a requirement since 2014−the guideline for bridges is from 2015 and the guideline for roadways and railways is from 2017. For FTIA, exchanging information between its software applications was one of the main motivations behind adopting BIM. Finnish representatives mentioned the concept of "liberating" data from vendor systems as a key driver for FTIA. The goal is the use of open BIM practices across all infrastructure life-cycle phases. FTIA has a BIM strategic roadmap based originally on the Norwegian roadmap developed for hospital buildings. The same maturity matrix is presented in 2017 by CEN—the European Committee for Standardization. The strategy identifies five levels of maturity (see Appendix D).

Current Efforts: BIM for infrastructure growth in FTIA is based on three foundational pillars:

- Creating guidelines.
- Creating knowledge.
- Providing tools.

FTIA is working with its industry partners including contractors, consultants, the software industry, and non-profit standards organizations such as buildingSMART International's Nordic chapter (buildingSMART Finland started as its own chapter in 2020) to advance BIM for infrastructure practices and meet the challenges related to its implementation.

Leading-edge Practices: FTIA's BIM for infrastructure unit—InfraBIM—is regarded as an early adopter of open BIM for infrastructure practices thanks to the national mandate and the government's goals. FTIA has established common InfraBIM requirements and developed an InfraBIM asset classification system and an open data exchange standard. The data exchange standard is called InfraModel and is based on LandXML. InfraModel is expected to be an integrated part of the process in all projects, creating value for different stakeholders. It is seen as a tool for efficient asset management through life-cycle applications.

FTIA routinely performs R&D efforts with Finnish academic partners, the Conference of European Directors (CEDR), and other international bodies to identify and implement tools and technologies to support BIM growth. In 2018, FTIA launched the Velho Alliance project—an online project and design asset information register and portal for roads, rail, and seaways intended for contractors and consultants to download and upload standardized design and construction data for projects. The project tries to meet the data management requirements set forth by the ISO 19650 standard.

Denmark/DRD

> **DRD's Primary Motivations**
>
> - Increased productivity of the construction sector
> - Supported by a non-specific government mandate
> - Strong alliance with the construction supply chain

BIM Context Awareness: DRD is an Executive Agency of the Ministry of Transport and is responsible for the State-owned roads in Denmark. DRD constructs, operates, and maintains a vital road network of almost 4,000 kilometers on which 45 percent of the entire road traffic in Denmark operates. Denmark has had a BIM mandate since 2007—one of the earliest adopters, but it did not include infrastructure. However, the mandate was non-specific, and the definition of BIM was open to interpretation. Hence, results to the mandate have been mixed. An ongoing five-year collaboration project called BIMInfra between two of the country's largest infrastructure owners, Banedanmark (rail authority) and DRD, began in 2018 to further develop the digital transformation of the infrastructure sector, based on international standardization work in the field. Specifically, the parties will collaborate on the use of digital BIM processes with the aim of increasing productivity in the construction sector. DRD has not received special funds to implement BIM. DRD has a life-cycle vision for BIM but is taking deliberate but small steps to achieve its grander vision of open BIM for infrastructure in accordance with a BIM implementation roadmap patterned after FTIA's roadmap. Like FTIA, DRD works with other public agencies and the Danish Association of Contractors and Danish Association of Consulting Engineers to advance BIM initiatives.

Current Efforts: DRD has executed several sub-projects within the digital project delivery domain to grow staff expertise, organizational acceptance, and experience with BIM. Examples include use of digital models for machine control, visualization, clash detection, use of digital notes and checklists, and live access to data during construction. The organization has predominantly worked with proprietary tools to accomplish its BIM objectives to date. However, it is working toward open BIM processes and is establishing information requirements, content of the digital models in a model standard, specifications about the model structure and how to communicate digitally, and model delivery agreements with consultants or contractors. DRD is also developing a computer-aided design (CAD) layer naming system as an interim step until object-based data models are developed to communicate model information, a classification system, and an object library.

Leading-edge Practices: Key staff in some agency units, e.g., bridges and roads, are encouraged to keep up with leading-edge practices related to BIM. For example, DRD is working on making 3D-engineered models as legal tender documents for construction. It participates in international committees and conferences and makes external contacts. Internal R&D activities to advance BIM and collaborations with universities are prevalent, though such encouragement is highly dependent on unit managers.

Sweden/Trafikverket

BIM Context Awareness: The Ministry of Infrastructure focuses on infrastructure, digital policy, and energy. Within this Ministry, the Swedish Transport Administration (Trafikverket) oversees roadways, railways, and ferries. For Trafikverket and the Ministry of Infrastructure, BIM is considered "business as usual." Despite the lack of clear-cut government guidelines for a long time, BIM has thrived in Sweden mainly as a result of informal alliances between public transportation clients and the construction sector. According to an interviewee from Trafikverket, the main motivation behind BIM maturity and growth in Sweden is the improved productivity gains it brings. Strategies of Trafikverket include harmonization of BIM, CAD, GIS, and project life-cycle management data; tracking information origin and quality throughout the life cycle; and leveraging these data throughout the procurement process. Requirements for such data are tool-neutral and based on open standards—Open BIM.

Trafikverket's Primary Motivations

- ❖ Increased productivity of the construction sector
- ❖ No binding government mandate at the beginning; taking shape since 2015
- ❖ Strong recognition of need for BIM in the construction supply chain
- ❖ Design (3D) model as a legal construction contract document
- ❖ Design model maintenance through construction for hand back

Current Strategies: Starting in 2015, Trafikverket mandated the use of BIM to facilitate nationwide implementation. In 2019, Trafikverket identified several targets to further the BIM practice, including:

- A common structure and hierarchy of assets based on CoClass (a national classification system) with asset breakdown hierarchy and unique identification of all assets.
- Information requirements for different phases according to level of detail, level of information.
- Information deliveries based on international, national, and Trafikverket-specific standards.

Trafikverket is keenly aware of the challenges facing wider BIM adoption in Sweden. For example, some of the challenges include harmonization of information captured from local projects (typically proprietary systems) with national systems that host asset information for specific purposes. Trafikverket is aware of the need for interoperability of data in accordance with international standards as well as training for project personnel and providing advanced and specific BIM support for major projects.

Leading-edge Practices: Trafikverket is a leader in adopting a new infrastructure classification system termed CoClass developed specifically to support 3D model-based representations of built infrastructure. CoClass was primarily developed to be compatible with BIM and is gaining international attention. Trafikverket is heavily invested in international standards development for infrastructure, including sponsorship and participation in buildingSMART's IFC standards development efforts and the development of BIM Collaboration Format and GML standards. Trafikverket is of the opinion that the following factors are key to successful implementation of BIM for infrastructure: (1) high level of ambition from the start; (2) competent BIM support staff on-site to assist with implementation with regular training sessions; (3) a common document management system; and (4) adopting BIM on large-scale projects that lend themselves to focus on improving methods and processes. Additionally, Trafikverket is a pioneer in using 3D models as contract documents that take precedence over other paper drawings and documents. They also pioneer the maintenance of the 3D model through construction, which is done either by the agency (on design-bid-build contracts) or by the contractor on design-build contracts. It was also discovered through interviews that, for the latter case, it was common for the contractor to hire the owner's engineering consultant (if one is available) to make model updates.

Norway/NPRA

NPRA's Primary Motivations

- Control of construction costs; in 2006, final project costs were 25 percent greater than engineers' estimates
- Supported by a government mandate
- Strong interest within the construction supply chain

BIM Awareness: The Ministry of Transport and Communications includes NPRA (Vegdirektoratet), which overseas public roadways. Awareness and adoption of BIM in Norway are due both to government requirements and "bottom-up" market adoption. In response to a wide discrepancy between projected and actual construction costs, in 2006, the Norwegian Road Administration proposed several initiatives: aerial scanning of terrain to reduce elevation errors; production of 3D models instead of drawings to reduce on-site errors; and definition of information requirements based on open BIM standard formats. In Norway, the primary means for agencies to communicate BIM requirements is through "BIM Manuals" that describe required submittals. These submittals include a description of deliverables (e.g., design 3D model) in native/proprietary and standardized file formats, the specific information to be provided, and other guidelines. NPRA began developing the V770 handbook for data model output in infrastructure projects in 2010 (called 138 Modellgrunnlag). Handbook V770 Modellgrunnlag was developed with the involvement of local contractors, consultants, surveyors, and software developers, which created tremendous "buy in" of BIM processes. The first edition of the handbook was released in 2012, followed by another in 2015. In terms of bridge and structural design infrastructure, Norway uses the N400 handbook released in 2015. This handbook allows for model-based design while simultaneously setting specific requirements, including using open BIM formats to ensure interoperability, expecting that the model be as precise as the drawings, and deriving survey control data from the 3D models. NPRA anticipates keeping some drawing types, but expects to exclude most. Further, all drawings are to be based on model data.

Current Efforts: At this moment, NPRA is working on revising the 2015 handbook to reflect evolving technology and markets. It is expected that post revision, 3D modeling with data output control will become a norm in all future road projects in Norway. Bane Nor, the Norwegian railway infrastructure agency, also started developing a new information standard—the KIM project—aimed at defining common requirements for information-based modeling based on BIM technology. It will describe the requirements for roads, railways, and other structures. Recognized Norwegian agencies offer training and certification for BIM users.

Leading-edge Practices: Norway is known for its leading-edge practices in BIM. For example, Nye Veier, the organization responsible for the construction of major roads in Norway (typically through design-build contracts) requires all information related to project delivery and O&M be contained in one information (BIM) model, while data are stored on integrated servers in open file standards. NPRA is using Unified Markup Language (UML) for modeling object classification. For this purpose, it used OGC and ISO TC-211[9] standards as the basis for developing national classification of object types. Additional ISO, OGC, and other open source standards are currently being evaluated and NPRA expects to complete this effort in 2021. The agency uses GIS for modeling network and conditions for asset management. NPRA opined that various data and information models may be needed to support various purposes; e.g., GIS-based asset management data models supported by the open GML standard and the linked data standard to model some aspects of the life cycle like O&M but perhaps not construction.

United Kingdom/Various Agencies

BIM Awareness: The UK has been a trailblazer in the movement to digitalize the construction sector. In 2011, the UK BIM Task Force, housed within the BEIS Ministry, produced the Government Construction Strategy report with specific provisions for BIM. A key requirement in this document is that construction suppliers tendering for centrally procured government projects in the UK be working at the now famous, BIM Level 2 (as defined by the Bew-Richards Maturity Model) by 2016. The overarching aim of implementing BIM Level 2 was to reduce the cost of government construction projects by 15 to 20 percent.

UK's Primary Motivations

- Lift performance of construction sector to improve economic output
- Supported by a government mandate
- Sustained national support for BIM initiatives

Given that approximately 40 percent of construction dollars in the UK are spent by the government (half of this, i.e., 20 percent, is procured by centrally located government agencies, e.g., Department for Transport and the Ministries of Justice and Defence), the UK Government recognized that it could leverage this buying power to get better value from public construction by 'upgrading' industry to digital workflows.

This government requirement was a joint coalition between the public and private sector. Government put in a small amount of seed funding (for information process standards development, communications activities, and training support to public clients introducing BIM standards for the first time to tenders).

Industry responded robustly to this policy and public procurement strategy. The collaboration led to a large increase in BIM adoption rates and BIM awareness in various public sectors involved in capital project delivery and asset management, including highways. A series of standards published by the British Standards Institute (BSI)—PAS 1192: Parts 1 through 6, set the requirements for the level of model detail (graphical content), model information (non-graphical content, such as specification data), model

[9] ISO/TC-211: Geographic information/Geomatics Standards for data management (including definition and description), acquiring, processing, analyzing, accessing, presenting and transferring data between users, systems and location. https://www.iso.org/committee/54904.html

definition (its meaning), and model information exchanges. The PAS standards drove the development of international BIM standards as codified in the 2019 ISO 19650-1 and 19650-2 standards.

For many, the UK BIM mandate is a major success story as it relates to how it drove the adoption of collaborative software tooling or work processes in project delivery even if the mandate did not extend to specific information requirements like those defined and codified by other European nations (e.g., the Netherlands and Finland).

Current and Leading-edge Efforts: The oversight of the UK BIM initiative has been transferred to the Centre for Digital Built Britain (CDBB)—which is a partnership between the BEIS and the University of Cambridge. The center is driving research to advance digital construction and smart asset management and operation notably in the development of UK-specific annexes for the ISO 19650 standards as they relate to the IM PAS 1192-3 (asset management) and PAS 1192-5 (cyber security while using BIM). The center also advocates moving away from the terms "BIM Level 3" and "BIM Level 4" to "operate and integrate" to better articulate the original intent of BIM—integration and interfacing of data from project delivery to service-delivery processes within secure information landscapes and across federated "digital twins." The focus is on targeting a 'National Digital Twin' construct, which would allow for communication between systems that have virtual equivalents, enabling simulation and optimization of decision making at the urban scale. Much of this work is expected to result in future British and international standards.

CDBB has an international program that partners with over 30 countries and governments in Europe, Latin America, and Asia to align strategies and standards (including ISO19650 series) in order to drive shared benefits and prosperity. Much of the UK's strategic BIM methodology and technical standards are packaged within the international program and appear in various adapted forms across the globe.

2.3 Performance Awareness and Applications of BIM for Infrastructure

The host organizations were interviewed to determine if and how they have documented the performance of the BIM for infrastructure processes they have implemented. Specifically, the following aspects were probed:

- How they aligned BIM for infrastructure performance goals with broader agency performance goals/measures.
- How they have assessed benefits, costs, and return on investment (ROI).
- What challenges and risks they have identified through the implementation process.

The Netherlands/RWS

Performance Goals and Measures: Gaining access to better quality information through BIM for infrastructure processes is one of the top two goals for asset management within RWS—explicitly tying it to the agency's strategic objectives. RWS is aiming to have BIM implemented widely for use in the registration of data/information by 2020, particularly for use in construction projects. BIM for infrastructure is also being practiced to supply information to maintenance management systems. RWS hopes to create virtual models of all its physical networks and tie traffic and traffic flow models with these networks. The information systems are expected to reach a standard that provides a quick and efficient overview of the entire network.

RWS' BIM Goals and Benefits

- Improved asset management by having asset information in control
- Linked to top two asset management agency goals
- ROI from BIM estimated at 2:1
- Have a roadmap for implementation
- *Key challenges identified*: alignment of data and systems across regions in accordance with standards, change management

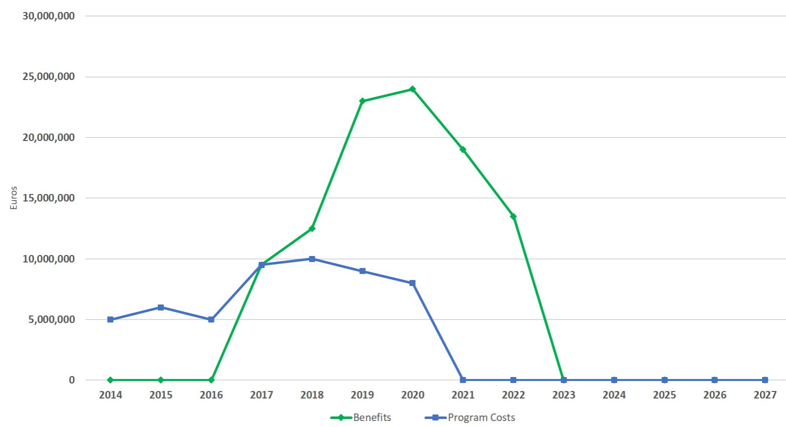
Benefit Quantification: RWS has made significant investments to implement BIM for infrastructure. Headquarters developed policies, procedures, systems, tools, and technology transfer processes, and implementation efforts have been conducted within the regions. The agency has spent millions of euros implementing BIM for infrastructure investments and has reported that ROI is several times higher with costs recovered through savings in construction projects. The greatest benefits according to RWS are in the following areas:

- Standardization of prefabrication and making the design process more efficient.
- Lower transaction costs because designs are produced faster using only broad outlines, which reduces the financial risks for tenderers.
- Early identification of construction errors and reduction in failure costs (which can be up to 11 percent of the total construction costs).

RWS has a formal process for assessing and recording benefits. Most benefits accrue because of superior information about assets and asset networks. Benefits are being tracked at three levels:

- Quantitative benefits: savings on transaction costs and cost avoidance in the design, construction, and operations phases due to inefficient data handling and decreasing data quality due to mistakes.
- Qualitative benefits: agency reputation, improved asset information (better quality of FAIR data) and improved strategic planning, more efficient and effective internal processes.
- Benefits accrued to third parties: contractors can use one system for all RWS contracts and consolidate their IT landscape, lower transaction costs, better quality of data.

Figure 2-1 shows the projected benefits and costs from implementing BIM that RWS has constructed (figure provided by RWS staff in 2016). The figure shows the program costs starting at €5M in 2014 and gradually increasing year-on-year to reach €10M in 2018, and subsequently diminishing before completely tapering off in 2021 when BIM for infrastructure is expected to be mainstreamed. The benefits lag the investments by about two years and start accruing in 2017, rising to €25M in 2020, and then declining as BIM for infrastructure is mainstreamed. According to figure 2-1, benefits stop accruing as BIM for infrastructure becomes the "new normal" within the organization. The ROI from figure 2-1 is approximately 2-to-1, i.e., the estimated benefits are twice the cost of implementation.



Source: Rijkswaterstaat, Ministry of Infrastructure and the Environment.

Figure 2-1. Chart. Projected benefits versus total program costs from BIM for infrastructure implementation—RWS.

Early benefits realized included:

- First BIM contracts showed a reduction in the number of change orders (2 percent versus 12 percent).
- BIM implementation increased awareness within the organization for the need to standardize data exchanges.
- BIM implementation increased awareness in project teams to validate data coming from construction to project and asset information management systems.
- Document procurement times were reduced by five times when compared to traditional processes.

Benefit quantification and quality on BIM projects to build support is a core activity at the agency and is completed by the research unit.

Challenges and Risks: RWS has an advanced understanding and first-hand experience with implementing BIM processes to deliver construction and maintenance projects. Agency staff revealed that some of the key challenges it faces are the alignment of information/data systems at the regional level and the central office. Another significant challenge is in organizational change management; in fact, significant effort goes into training, educating, and providing technical assistance to project staff. One host participant likened the roll out of working with improving standards and processes while delivering projects as "building a bridge while walking on it."

Finland/FTIA

Performance Goals and Measures: BIM for infrastructure is aligned with meeting regulatory requirements. FTIA, along with a handful of major cities, make up a powerful group of public procurers who drive BIM requirements on projects. FTIA's approach is a close collaboration between the government and private sectors to evolve BIM maturity in Finland. FTIA has clear goals and a plan to accomplish various levels of BIM maturity over time. For example, FTIA assessed itself as being at Level 1.5 on its BIM maturity scale with a clear goal to evolve to Level 2 by year 2021 and 3+ by 2025. The agency is making significant progress in this regard in accordance with its roadmap (see Appendix D).

FTIA's BIM Goals and Benefits

- Improve whole life-cycle asset management
- 20 percent savings on construction costs on a major pilot; have a goal to measure benefits
- Have a roadmap for implementation; currently self-assessed at Level 1.5 of 4
- *Key challenges identified*: cultural shift, identification of champions, ensuring use of information delivered

Benefits Quantification: FTIA has had several pilot projects focused primarily on migrating information from design to construction and the hand back from construction for asset management use. The agency cited a major railroad project, Pasila-Riihimäki, and road project, Highway 4. Projects recorded a 15-20 percent savings on the cost of construction by using BIM process. Time savings and improved safety and quality were cited as the key contributors to the total savings realized on this project. The BIM information model was used for quantities. The model was checked every week and payments were made based on a real-time model. FTIA assumed the payment risk. This complex project was performed in an urban environment that used BIM processes to maintain four tracks were always open during the reconstruction of a seven-track railway line. Despite the documentation of benefits on such projects, FTIA does not appear to have an accepted agencywide process for evaluating benefits and costs associated with performance-enhancing practices and innovation associated with BIM.

Challenges and Risks: Cultural shift was cited as a major challenge for implementing BIM within FTIA. The FTIA representative identified BIM champion project managers who were able to bring along their peers during project execution as one of the keys to success for BIM growth. When FTIA started on the BIM initiative, it got push back from the construction industry around the idea that "you don't use it, but you require it." The FTIA representative opined that while setting more aspirational requirements to push yourself is good, agencies must be prepared to use the information they request.

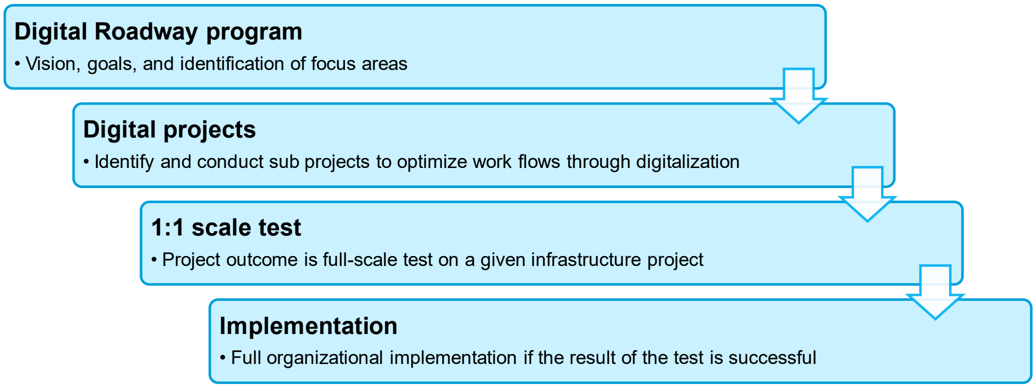
Denmark/DRD

Performance Goals and Measures: BIMInfra set a 5-year national BIM strategy in motion in 2017. The focus of this strategy is to improve information management with a life-cycle focus. The strategy is based on the FTIA's roadmap (see appendix D). DRD aims to achieve a Level 3 by 2022 by working closely with the industry to ensure that information about built infrastructure (3D objects) from construction is handed over in a form that asset management and O&M can use. However, the current focus is on the design and construction phase. DRD is planning to move to a model-based project delivery process; the goal is not to eliminate paper but to ensure that information can be moved efficiently using digital processes as much as possible. This means that any paper drawings required at any phase of a project must be backed up by a digital model. The agency is also adopting a model maturity level index framework based on the Nordic life-cycle standard (like the Level of Development in the U.S.). These model maturity index definitions help measure the maturity of the information model (e.g., 3D model) by modeling discipline (e.g., civil, structural.) as a function of what is modeled, and the quality of the data used to create the model to reduce uncertainty and improve communication during project delivery.

DRD's BIM Goals and Benefits

- Initial goal—digital project delivery
- Subsequent goal—link to asset management subsequent goal
- Currently advancing model-based design
- Roadmap follows Nordic capability maturity; at Level 1.5 of 4
- *Key challenges identified*: lack of dedicated funding, slow progress due to organic growth

Driven by this larger BIM strategy, DRD is taking a systematic approach to BIM implementation. Figure 2-2 illustrates this approach. Important aspects of this approach are: (1) identifying and conducting sub projects that gradually advance BIM (e.g., digital model for machine control, visualization, access to model data, practicing a common data environment, subsurface utilities in 3D, digital notes and checklists, CAD layer structure for each discipline); and (2) creating the wider foundation to implement BIM, including requirements definitions; classification of BIM objects, and information delivery specifications. DRD is working with the industry to prioritize pilot projects to advance principles around object-based BIM and related requirements. It is also looking to determine/commit to an object classification system to use for organizing information.



Source: Vejdirektoratet, Danish Road Directorate (DRD). 2019.

Figure 2-2. Illustration. DRD's approach to BIM.

Benefits Quantification: DRD has not shared any specific benefits from "real world" or pilot implementations of BIM for infrastructure, although the agency expressed interest in the topic and is looking for a framework for quantifying benefits. It emphasized the need for a simple measurement tool.

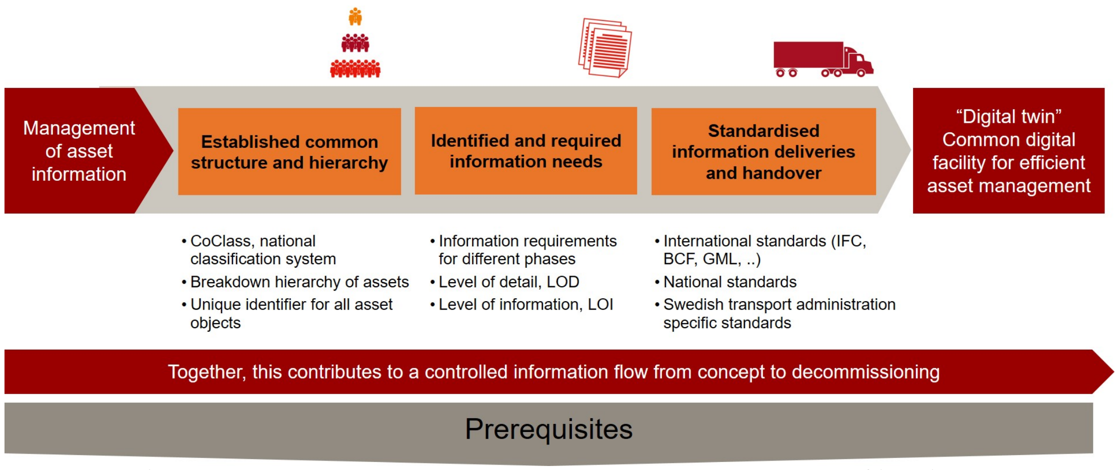
Challenges and Risks: Representatives from DRD emphasized the need to tackle the issue of the lack of a dedicated BIM program or funding. Within DRD, where BIM efforts are mainly led by design; the agency supports the thoughts and ideas BIM champions have to the extent possible and work with internal and external partners to make them relevant to the overall BIM context. DRD emphasized small steps to achieving the greater goal of BIM.

Sweden/Trafikverket

Performance Goals and Measures: Trafikverket's major goal is to become vendor-neutral across all its major infrastructure classes—roads and bridges, rail, and waterways. Digital asset information acquisition is currently a part of the procurement process that aims to use vendor-neutral, open standards-based information delivery by harmonizing and balancing the diverse standards that exist—BIM, CAD, GIS, and project life-cycle management. Trafikverket's BIM strategy was inspired by the work done by the British Standards Institutes' PAS 1192-2 standard. The short-term goal, which began in 2015, was to ensure all public infrastructure investments require the use of BIM at a minimum defined level. At this level, BIM was 3D CAD for design and construction and object-based storage in different AIM systems. The long-term goal is to handle all asset information from a life-cycle perspective in a format that is both human and machine-readable. Figure 2-3 presents Trafikverket's BIM-related targets set in 2019. The agency is actively moving away from the term BIM and to the term "Information Management."

Trafikverket's BIM Goals and Benefits

- ❖ Whole life-cycle asset information management including BIM, CAD, GIS
- ❖ Create "digital twin" for efficient asset management
- ❖ Establishing common structure and hierarchy of assets and information requirement and ensuring internal competence



Source: Karin Anderson, Senior BIM Manager, Major Investment Projects, Trafikverket, Sweden (2019)

Figure 2-3. Illustration. BIM targets of Trafikverket (circa 2019).

Benefits Quantification: All the discussions regarding benefits were qualitative in nature with no actual quantified savings documented for either the E4 Stockholm Bypass Project or other projects. Trafikverket does not appear to have a benefit quantification tool in place; however, the agency described a large and complex ongoing project—the E4 Stockholm Bypass Project connecting the northern and southern parts of Stockholm—to showcase the potential benefits of BIM. This 10-year project involves more than 13 contractors and is roughly 18 miles long with 11.2 miles of the project involving tunnel construction. The main innovation in the project is the use of the models as contract documents. The project aimed to implement BIM from the beginning and to have object-oriented models as the contractual documents. Very few drawings were produced. The bid packages were a mix in terms of level of information or detail; some contained detailed design documentation while others had a certain amount of detailed design to be done by the contractor.

Contractors from multiple countries will be involved during construction with their own choices of design tools for the detailed design still to be done. They have the choice to define their own strategy for the design and build. However, models are expected to be delivered and updated frequently in an open BIM, vendor-neutral format. Coordination models containing all disciplines are expected to achieve the following benefits:

- Better quality review and therefore fewer errors when compared to traditional paper drawings.
- Lower project cost estimates through more accurate bill-of-quantities.
- Fewer change orders during construction due to errors in design.

Challenges and Risks: The agency is keenly aware of the challenges that lie ahead in terms of meeting its long-term goals—handling all data from a life-cycle perspective—like a "digital twin" of physical infrastructure. It recognizes that more work needs to be done in three specific areas:

- Establishing a common structure identification and hierarchy—CoClass—the new Swedish classification system for all built assets—helps in this regard but significant work to map the information between project information models and asset information models will be needed.

- Defined need for information—Trafikverket has a set of requirements that is complete in some parts already, but it needs to be harmonized and supplemented in several technology areas. For example, it is still unclear which objects with associated attributes/properties should be in a design information (or BIM) model and which information should be passed on to asset information systems. Both the level of detail and level of information to be maintained within the various object-based information models must be defined more carefully.
- Standardized information exchange—Trafikverket currently lacks standards for transferring information from project delivery activities to asset information management. Many project delivery activities of BIM models currently take place in proprietary formats, which is unsustainable in the long run. Trafikverket is actively participating in the international standardization work that is underway to develop standards in infrastructure for roads, railways, bridges, and tunnels (e.g., IFC, GML).

The agency also recognizes that some prerequisites need to be in place before BIM or "information management" can be mainstreamed within Trafikverket:

- Conditions should support legal use of digital information for all stages of the life cycle, including for archiving and preservation.
- Given that Sweden invites the participation of outside supply chain participants in its construction work, aligning Trafikverket's application of BIM with the outside world is seen as a critical activity.
- Trafikverket realizes the need to ensure that internal competence regarding information management according to the principles of BIM is a work in progress.

The agency is taking action on all these fronts to ensure the success of BIM for infrastructure.

Norway/NPRA

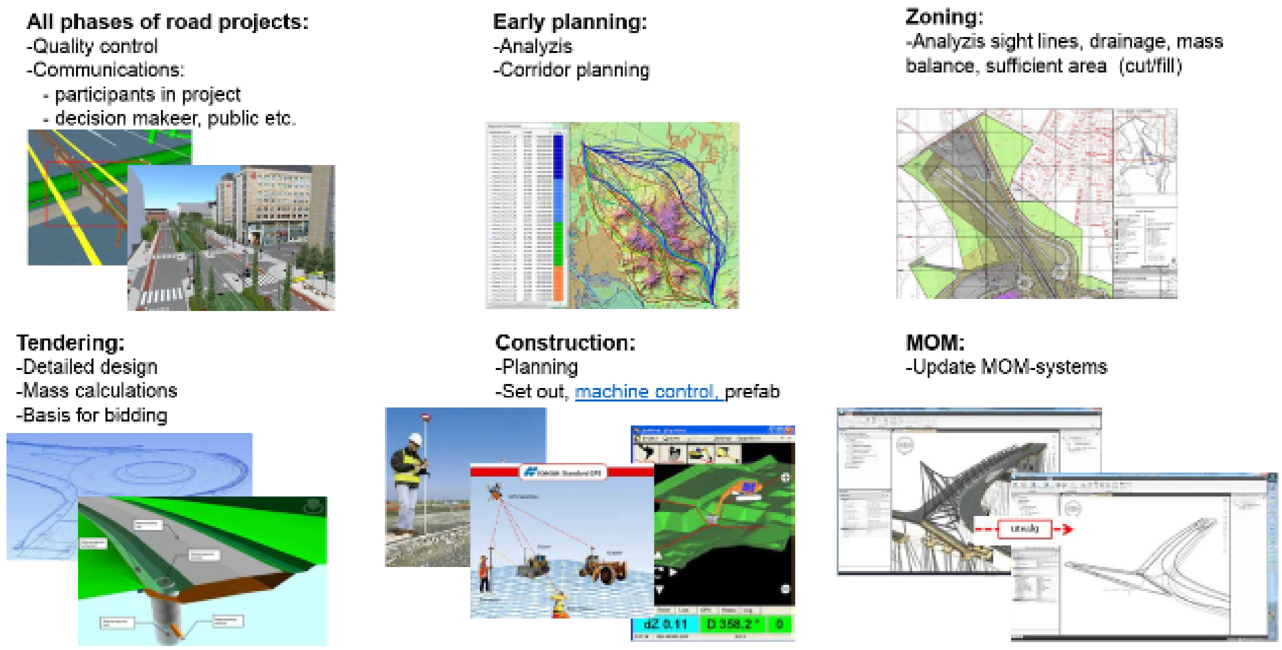
Performance Goals and Measures: NPRA's BIM program is primarily targeted to reduce design errors, errors in basis data used for preliminary scoping activities, and zoning errors. The agency has been on a relentless march to improve the situation since 2006. For infrastructure projects, the agency's overall goal is to "Build it twice, digitally first." Figure 2-4 illustrates how NPRA uses different information models across the various asset life-cycle stages. Note the use of both GIS and 3D-engineered models. The agency has clear-cut goals related to BIM efforts:

- Prepare and update a handbook (Handbook V770 Modellgrunnlag) to describe production and work processes based on models and reduce on-site errors. The latest update of this handbook is due in 2021.

NPRA's BIM Goals and Benefits

- ❖ Reduce design errors in basis data used in preliminary scoping "build twice, digitally first"
- ❖ Benefits of BIM clearly established on multiple projects
- ❖ Multi-standard model to deliver information across life cycle
- ❖ Unique approach to ensure software tool availability to deliver information per classification system (UML modeling)

- Develop conceptual information models using Unified Modeling Language (UML)[10] modeling principles based on national and international standards (e.g., ISO/TC-211 standards for data management and definition, ISO 19103[11] rules for documenting conceptual schema of data that describes geographic information). The UML-models will contain object names, definitions, properties, and, to some extent relations, design parameters and business processes (like quality control). The UML-models can be imported to software (e.g., CAD software, GIS software) based on XSD-schemas. Then data modeled in CAD software and other software can be exported to open formats. NPRA plans to investigate export to and use of GML-formats in particular, since these formats are well suited for the operations and maintenance.



MOM = maintenance and operations model.

Source: Norwegian Public Road Authority

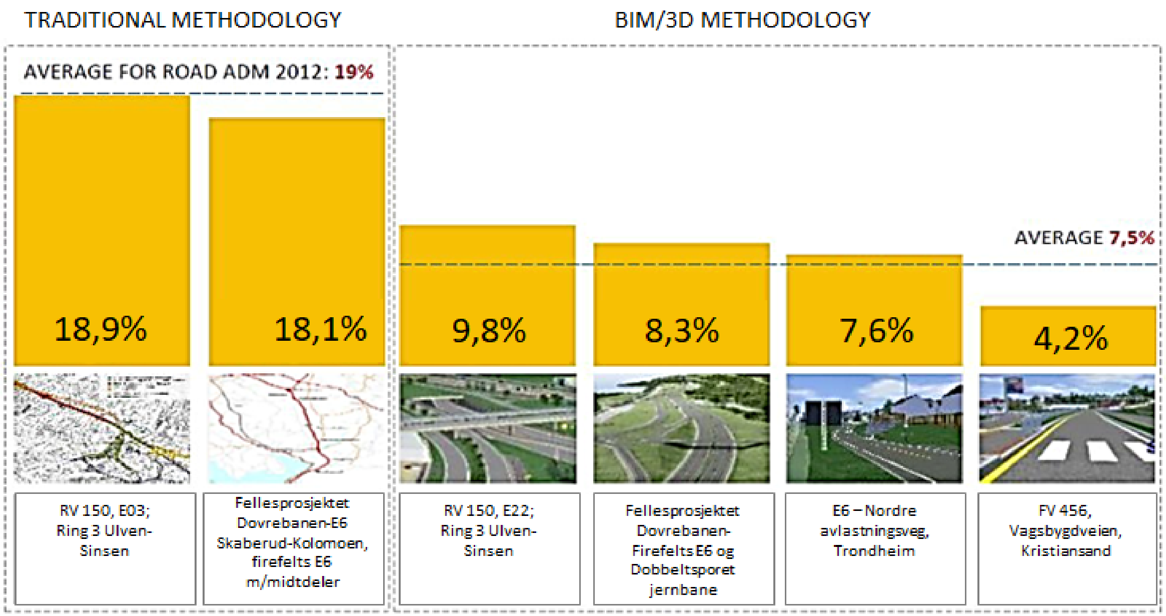
Figure 2-4. Illustration. Model uses according to NPRA.

Benefits Quantification: NPRA has documented evidence of benefits from implementing BIM. Based on field studies documented in two reports, the agency is convinced that BIM reduces the number of change orders and construction costs. Figure 2-5 and figure 2-6 present the cost effects of using BIM.

Figure 2-5 compares the value of change orders as a percentage of construction costs for projects delivered traditionally using drawings versus those delivered using 3D models and BIM Level 2 information standards in 2013. The figure shows that model-based projects consistently resulted in a lower value of change orders. On average, BIM-based projects produced a net savings of 11.5 percent of total construction costs for the agency. Even though this was relatively early in the development of a

[10] Unified Modeling Language (UML) https://www.uml.org/
[11] ISO 19103 Geographic Information Schema Language. https://www.iso.org/standard/56734.html?browse=tc

model-based working method in Norway, NPRA concludes that model-based projects had fewer deviations because of their ability to communicate better basis and engineering data from design to construction. NPRA expects change orders due to errors in basis data or projected data will be insignificant for projects currently using the V770 Handbook method. Note that this comparison disregards uncertainty in the data because of geotechnical risks, which is handled using separate rules.



Reference: Norwegian Road Administration in coop. with Vianova Systems AS, 2013.

Figure 2-5. Chart. Reduction in change orders—traditional methods vs. BIM Level 2 methods based on 3D modeling on various Norwegian road projects.

Figure 2-6 compares the cost efficiencies created by switching the production environment in a very large public infrastructure project to a model-basis as opposed to a drawing basis. The figure shows that while modeling costs increased, dramatically at first and modestly later, the costs for drawings dropped. Therefore, the total cost of the detailed design phase of the project recorded a net saving. Changes to models during production results in much lower costs when compared to preparing production drawings as a result of changes.

Source: BaneNOR

Figure 2-6. Chart. Cost effects of model-based design.

Challenges and Risks: NPRA is keenly aware that clear definition of information requirements and modeling guidelines are critical to the successful implementation of BIM processes. It is also aware of the availability of software tools to deliver information as per the classification. To this extent, NPRA works with software vendors to foster implementation and scale its classification to the pressing needs at any given time. NPRA, Bane NOR, and other infrastructure partners also understand the importance of training and certification to mature BIM practices across the country.

United Kingdom/Various Agencies

Performance Goals and Measures: According to the organizers of the UK portion of the tour, the UK BIM mandate target of BIM Level 2 by 2016 as defined by the Bew-Richards Maturity Model was more an aspirational goal to move the construction sector to a better place in terms of productivity. The organizers felt that, although not specifically measured or enforced, this goal was largely met by the various client organizations and their supply-chain participants. However, given that the UK BIM mandate did not cover specific information requirements or information modeling processes like those defined and codified by other European countries, it was left to the market parties in the various infrastructure sectors to define information requirements and deliveries within their contracts and carry forward the "spirit" of the mandate. In the UK, this approach was 'by design,' based on the premise that each client would have information requirements particular to their needs and that more important was a standard process to defining information need and delivery

UK's BIM Goals and Benefits

- BIM was used as a Governmental policy lever to improve competitiveness and productivity of construction sector
- Empirical data suggests that Level 2 BIM maturity met and benefits derived
- Diverse implementation of the "spirit" of the UK BIM mandate across UK
- Sustain momentum and drive greater standardization and maturity

mechanism. The limitations of a 'fixed information requirement' was a 'learning' of the early research that led to the UK BIM program.

Benefits Quantification: UK invested $7.5M over a five-year period to advance BIM. The money was spent on: (1) having an implementation team coaching the government departments in the adoption of the BIM processes; (2) using a standards department (British Standards Institute) to bring industry stakeholders together to build the necessary 'information management' standards; (3) execute a communications strategy to encourage industry take-up of standards; and (4) rollout of an implementation strategy across central public projects. The ROI from BIM was not calculated formally for the entire country, but the UK study tour hosts estimated that it may be around 10 to 15 percent, with the value being created in the supply chain. A participant from the Environmental Agency described the benefits of BIM in terms of having access to the agency's own data. She described that the situation prior to BIM was so bad that "only 20 percent" of the agency's data were accessible due to the siloed system. The agency set about changing this with BIM. The UK study tour organizers felt that BIM is a means to an end and that the ROI should not be overly emphasized. They urged that BIM should be treated like any digital process, e.g., a digital camera over 35 mm film or email over postal mail.

Challenges and Risks: Several of the UK presenters noted that for BIM to enter mainstream culture, the implementing agency needs to be proactive and make it work for all internal stakeholders and their partners, which means convincing people who are busy that this is something that they should want and do even if they do not see an immediate benefit. This emphasizes the need for a clear vision of the implementing agency: a clear 'why' driver is essential. The UK study tour hosts also noted that the construction industry has a wide range of companies unlike industries like the automobile industry that makes it harder to adopt BIM uniformly, without the action of public clients. For example, unlike the automobile industry, if one company moves toward automation in construction, the industry would not necessarily follow. The UK hosts also felt that it is the client's job to articulate what it needs. There are many people in the construction supply chain who would be using the outputs of BIM but would not need to know about BIM. Therefore, the key is to talk about outcomes.

The participants also felt that the UK Level 2 BIM mandate was a double-edged sword. The mandate motivated action and simultaneously stalled the drive to do more once Level 2 was achieved. This recognition of a longer-term vision contributed to the launch of the Centre for Digital Built Britain and the Transforming Infrastructure Performance Report. A lesson learned is perhaps that sharp focus on interim milestones when looking to achieve a grander vision may be counterproductive if a longer-term 'stretch' target is not fully communicated.

2.4 Supportive Systems and Staffing to Enable BIM for Infrastructure

Discussions with the host organizations were used to assess the commitment of their respective organizations to continuous improvement, willingness to invest time and financial resources in beneficial innovation like BIM for infrastructure, and their willingness to take prudent risks and learn and adjust from experience. The study team also asked how each agency was fostering knowledge management within the organization, specifically, around the topics of:

- Access to funding.
- Institutional knowledge management.
- Staff capacity.
- Agency pilot testing.

The Netherlands/RWS

BIM initiatives initially funded as an innovation program in 2012 are now housed under a fully funded AIRBIM program at RWS. AIRBIM strives to align data and information in asset management systems with those in design and construction systems. The goal is to have asset information in control to ensure optimal system O&M and good quality strategic planning—a big BIM view. The evolutionary path that the program followed indicates the extent to which the RWS board is convinced of the benefits of BIM for infrastructure and is willing to commit to it in terms of leadership support and funding.

RWS's BIM Supportive Systems and Staffing

- Funded AIRBIM program
- Expertise at headquarters and on projects—business and IT related
- Several years of work focused on refining data exchange standards and processes, data structure, central repository, data modeling and linking
- Piloted BIM on nearly two dozen major capital projects and a few maintenance projects
- Committed to staff training

RWS is a foremost leader in developing and setting data and process standards within the Dutch infrastructure industry. They have a unique advantage of skilled BIM experts who understand the business and database. Specifically, the agency has developed the following:

- Uniform data-exchange standards with contractors, e.g., COINS (container with structured and unstructured data) and VISI (process of exchange).
- Definition of data-structure including data need (or OTL) for information coming back to the agency from construction or maintenance operations.
- Verification and validation of data on entry (preserve clean state).
- Single source of truth in a central repository.
- Data delivery into functional RWS applications (GIS, Enterprise Asset Management systems).
- A system that supports one uniform work process over regions.
- Integration of data from personal/project/regions to national data archives.

RWS had six senior data modelers and database administrators who were involved in redesigning their data models and migrating legacy data models to newly defined open, shareable BIM models—an extremely complicated task. A key advantage was that the data modelers understood business data making the task somewhat simpler. Underscoring the complexity of mapping legacy data into the new OTL, RWS noted that it took 10 months to agree on principles of modeling and years of work to migrate data into new data structures. Yet, they highlighted that a key lesson learned was to keep the transition from legacy data structures to new data structures as short as possible to avoid implementation pitfalls.

In addition, for project execution, RWS has well-defined knowledge, skills, and abilities requirements for the most common BIM roles in the Dutch construction projects to either educate existing employees or bring on new employees. Defined roles include BIM project manager, BIM team manager, BIM coordinator, and BIM modeler. RWS has piloted BIM standards and workflows on more than two dozen capital highway infrastructure projects and, more importantly, on a handful of maintenance projects (at least three known to the research team). Not only have the existing standards, processes, IT technologies, and tools been refined as a result of these projects, the level of coordination and challenges that exist in implementing BIM across the various regions of RWS are also understood.

Finland/FTIA

At FTIA, because BIM initiatives are backed by the broader goals of the Finnish government around improving information management, funding and substantial support are available. Highlights of this support are noted below:

FTIA's BIM Supportive Systems and Staffing

- ❖ Has a funded and dedicated BIM program
- ❖ BIM = open standards at FTIA
- ❖ Focused on creating information requirements, guidelines for information delivery in projects, and BIM tools and services to exchange data between market parties
- ❖ Pilot BIM on several rail and road projects (including bridges)
- ❖ Committed to staff training

- A dedicated BIM program within the organization (InfraBIM) is responsible for the oversight of all open BIM research and development as well as coordination activities within the highways sector.
- Senior management at the organization is strongly committed to supporting and developing BIM for infrastructure. Well-planned and executed activities show the commitment of the organization to meet its goal.
- FTIA's BIM strategy is predicated on open common standards, and the vision is decidedly "big BIM" in that it encourages enrichment of information from general infrastructure planning to infrastructure and real-time operations management.
- The agency has developed or is actively developing the knowledge base required for BIM for infrastructure to be mainstreamed. For example, it has developed the following:
    - BIM standards for information requirements, information formats (e.g., LandXML, GML, IFC,) and coding.
    - BIM guidelines for bridges and roadways, and project bidding documents with information modeling (including level of detail) delivery specifications for contractors.
    - BIM tools and services to check and accept work by third parties (consultants and contractors) and a road information register (Velho).

FTIA is actively conducting BIM pilots on major capital improvement projects that are being delivered using BIM workflows. Many of these projects are railroad projects that include highway infrastructure elements (bridges, tunnels), although some highway projects were cited. These pilot projects are being supported by digital coordinators and BIM teams. The role of the digital coordinator is to coordinate the digital plan with the master plan of the project and validate the quality of data. Enterprise tools allow various model views of the fused coordination model and allow project data to be stored in a database. The BIM teams assist with BIM specific design, construction, and asset management workflows. The agency appears to be committed to training its internal staff as well as the wider consultant, contractor, and software vendor community to achieve its bigger vision of improving the efficiency of information management in Finland's built environment.

Denmark/DRD

Unlike in RWS and FTIA, a dedicated cross-departmental BIM group within DRD does not exist. However, there is good support for BIM activities within the Design section and its senior management. Multiple champions within the Design section are liaising with their counterparts in the Survey, Construction, and O&M sections to drive the growth of BIM across various units of the organization. These champions are creating a wide foundation for BIM to succeed, preparing for and ensuring "small wins" for various stakeholders across the organization, educating internal and external stakeholders, and collaborating with other interested groups nationally (e.g., rail) and internationally to raise awareness of BIM workflows and processes. In advancing the BIM initiative, DRD has accomplished the following to date:

- Developed a model standard, including documenting the content of digital models produced in design.
- Developed technical specifications that describe the model structure and how digital information is communicated between market parties (clients, consultants, and contractors).
- Developed digital model delivery agreement with consultants or contractors to ensure that the agency model standard is being followed and that data can be used directly by other parties.
- Developed a common data environment to share data continuously with all participants project.

DRD's BIM Supportive Systems and Staffing

- ❖ Does not have a funded program; funding and leadership are at unit level, e.g., design
- ❖ Executing a sequence of small pilots to test and improve capacity, build confidence, and generate "buy in"
- ❖ Focused on developing model-based project delivery at the moment using proprietary design and construction management tools
- ❖ Evolving to open, shareable information exchanges in consultation with industry; some fundamental work completed

Figure 2-7 presents the digital delivery processes being developed at DRD to ensure that digital models are advanced from design to construction and back using standard procedures and procurement practices.

While the agency's digital model process is informed by CAD standards, DRD is preparing, in collaboration with other public sector clients and private industry within Denmark and other Nordic countries, European nations, and international standards organizations, for a future open information-exchange process based on documented information requirements during project delivery and asset management, an object-based classification structure for assets, and vendor-neutral information exchange formats and specifications.

Source: Vejdirektoratet, Danish Road Directorate (DRD). 2019.

Figure 2-7. Illustration. Digital delivery processes at DRD.

Sweden/Trafikverket

Since 2015, Trafikverket has required the use of BIM in all public procurements, which has had a major impact on the industry because the organization is the largest client for construction works in Sweden. Trafikverket has also assumed a leading role in bringing along the entire construction industry to adopt its BIM strategy. It has and continues to expend efforts in three main areas:

- Addressing legal and security issues to develop the legal basis to use digital information for all stages of the life cycle, including for archiving and preservation and to transact data in a secure manner.
- Fostering external collaboration to ensure that the application of BIM is in line with the outside world.
- Training and follow-up to ensure internal competence within the organization regarding information management according to principles for BIM.

The agency is piloting BIM on a major project and is committed to: (1) developing skills and knowledge; (2) collecting feedback from project staff to improve processes

Trafikverket's BIM Supportive Systems and Staffing

- ❖ Does not have a dedicated, funded BIM program; but funding BIM initiatives on major projects
- ❖ Piloting BIM on a major, complex project of national importance (ongoing)
- ❖ Focused on developing BIM policies, processes, legal basis, and people within organization
- ❖ Evolving to a future open, shareable BIM model

and tools; and (3) evolving procurement requirements based on this effort. The agency is actively working to get its different departments working with BIM from a common point of view. In the long-term, Trafikverket is working toward efficient data flows between GIS, projects using BIM, and asset management systems (see figure 2-8). Trafikverket works with other public clients and the private sector in the BIM Alliance Sweden to address issues concerning the built environment.

Source: Karin Anderson, Senior BIM Manager, Major Investment Projects, Trafikverket, Sweden (2019)

Figure 2-8. Illustration. Information exchange between BIM project repositories and object-based systems of record: outlook for Trafikverket.

Norway/NPRA

At NPRA, the BIM program has been an unqualified success. Bottom-up initiatives have demonstrated that BIM-based processes and model-based workflows result in cost savings for the agency. Since 2012, the agency has delivered several hundred projects using BIM-based standardized processes, workflows, and procedures. Some of these have been scrutinized to assess cost savings. However, not all previous work used open standards. For example, on past projects, while object-based approaches were used to ensure better information exchange across life-cycle phases, the information was not standardized. A mix of open and proprietary formats were used on these projects because there is no open, standardized format that holds all information that is created using engineering software. NPRA plans to continue with this practice of information exchange using both proprietary and open formats until more standardization support is available. However, in the interim NPRA is demanding a certain amount of standardization in the proprietary formats, for example, in the breakdown structure of a road project and object structure of each model type. To enforce this, UML models are being developed for these object

NPRA's BIM Supportive Systems and Staffing

- ❖ Has a dedicated BIM program
- ❖ Has been practicing BIM on actual projects using NPRA standards since 2013 using proprietary and open standards
- ❖ Developing new handbook based on open standards and new information classification based on UML modeling
- ❖ Evolving to a higher level of automation using BIM in the next few years

structures, instead of capturing these object definitions as text in a handbook. Regardless of whether the standards used are open or proprietary or limited to certain aspects of OTL, NPRA's projects have demonstrated the value of BIM to the agency. The agency is convinced and committed to funding further efforts in BIM to improve guidance development and standardization across the agency to align with open BIM standards and ongoing international work. Current efforts, including large, multi-year, multi-stakeholder efforts, are evidence of the agency's commitment to BIM:

- Creation of a new handbook that involves revising and merging two existing handbooks—V770 Model Basis and R700 Drawing Basis into a new guideline. This new guideline is expected to change the requirements for content and presentation for any drawings that remain to a model-based work methodology. The new handbook will lay out the requirements for basic data, and models will be mandatory in all road projects. The new handbook will build on the immense experience the agency has collected in the road sector since the inception of BIM-based workflows.
- Development of internal standards and, where appropriate, adoption of standards to ensure that the information that flows through different phases of a road project is available in a structured, documented, and preferably machine-readable way. NPRA standardization efforts currently involve (1) developing UML models of information about objects, their relationships, properties, and specifications; (2) development of specifications for information deliverables; (3) development of XSD-schemas that are machine-readable so that UML-modeled data can be implemented in software; and (4) development of GML as an information exchange format (as mentioned earlier, in 2021, NPRA plans to investigate export to and use of GML-formats in particular, since these formats are well suited for the operations and maintenance). At the same time, NPRA is watching other relevant emerging international standards, e.g., standards for organizing information from ISO and CEN, geodata standards from OGC, and BIM standards (e.g., buildingSMART's IFC). In particular, NPRA has evaluated the buildingSMART method of modeling and organizing information several times in the past (2006, 2012, 2016), and chosen different methods and standards each time, leading to the current practice that involves use of multiple open and proprietary standards (e.g., ISO/TC 211, ISO 19103 UML) for OTL definition, data management, and model specification. In 2021, as NPRA embarks on the journey of evaluating GML and other open formats, it will assess how the current information modeling and specification requirements will be supported by these standards.

United Kingdom/Various Agencies

> **UK's BIM Supportive Systems and Staffing**
>
> - Continued emphasis on developing BIM as a government strategy beyond Level 2
> - Government funding helping align international standards and UK standards around BIM, education, and awareness
> - Several BIM-based projects delivered to date—a majority using proprietary tools and technologies
> - Working toward open BIM practices

As was clear from the discussions with the primary UK hosts, the overall progression of BIM development within public client organizations was driven primarily by the UK government's strategy to require open, shareable asset information enabled by BIM on all publicly procured infrastructure projects. The strategic value of the BIM strategy was to improve the productivity and competitiveness of the UK construction sector globally. The UK government is not prescriptive in how public agencies should go about implementing BIM work methods on projects. Rather, its philosophy is to create conditions through government policy to allow public agencies and the private sector to invest more rapidly in the development of their own capabilities. However, the government made a modest amount of funding available to develop standards and protocols that implementing public clients within the UK have benefited from. These investments resulted in the creation of BIM standards (e.g., BS 1192 (Principles), PAS 1192-2, 1192-3, 1192-4, and the BS 8541 series). These standards include data standards, file naming standards, common data environment standards, common employer information requirements, and asset information requirements, etc. The PAS and BS standards played an influential role in the development of the ISO 19650 international standard for managing information across the whole life cycle of a built asset using BIM. They helped develop the BIM protocol—a standardized supplementary legal agreement that can be incorporated into construction contracts very easily to enable the production of information models.

While no direct conversations were held with staff from Highways England during the study tour, a glimpse of how public agencies were maturing their BIM processes, people, tools, and technologies was offered by the presentation made by the Environment Agency. Presentations made by various consultants on specific BIM projects within the rail, transit rail, aviation, and highway sectors also provided a secondhand view of the state of the BIM maturity in the UK. Better definition of requirements, improved classification on asset objects, 3D model-based workflows, common data environments and secure information exchanges, and GIS-BIM data integrations were all demonstrated. Although, several of the examples presented were "closed BIM" in nature, in that the data exchanges were still being done using proprietary tools, there appears to be a movement to open BIM concepts.

Overall, thanks to the wider government strategy, senior management at public clients understand the value of BIM and are committing to supporting BIM initiatives to move beyond the initial mandate of BIM Level 2 and embrace higher levels of digital workflows.

Agencywide or externally imposed government-wide policy-level impediments (in areas such as IT, human resources, outsourcing, and out-of-State travel) are interpreted as insurmountable barriers to advancing innovation.

2.5 External Collaboration

Considering that innovation, especially one that affects an entire supply chain and value chain, cannot occur without collaborations with external partners, openness to such collaborations and the degree to which they are practiced is a good indicator of where an agency may be placed with respect to BIM. The maturity of the host organizations with respect to external collaborations was examined along the following three dimensions:

- Interaction with peer agencies within the country.
- Communications with supply chain partners including consultants, contractors, and software vendors.
- Communications across national boundaries.

All the host organizations that participated in the study tours had active collaborations at the national and international levels.

Table 2-2 presents the types of collaborations these agencies are involved in nationally with other public clients and with other supply chain partners as well as international. Common themes derived from interactions regarding external collaborations are as follows:

- It is critical to have public clients have a national collaboration among themselves to set the tone for BIM requirements and unify around BIM procurements as they relate to engineering services or software procurements. Most countries are well organized in this manner.
- It is vitally important for public clients to support and participate in larger industry forums within their countries to engage with the private sector actors such as consultants, contractors, software vendors, or suppliers. From a public sector perspective, these forums are important avenues for communicating public policy or intent, tackle industry issues, seek broader cooperation for regulatory changes, develop national standards, adopt international standards, share knowledge, and foster innovation.
- Public client organizations should participate and become a proactive member in international organizations developing BIM standards or conducting BIM-related research and development to ensure that any national efforts undertaken are not duplicative and can leverage international resources.

Table 2-2. Activities undertaken by the study tour hosts related to BIM collaborations.

Activity	The Netherlands (RWS)	Finland (FTIA)	Sweden (Trafikverket)	Denmark (DRD)	Norway (NPRA & Bane NOR)	UK (Various)
Coordination among peer agencies within country	Road, Water	Road, Rail, Water	Road, Rail, Water	Road, Rail	Road, Rail	All public sector clients
Collaborations with the private sector	BIM Loket, NEN	buildingSMART Finland Infra room	Sweden BIM Alliance, bSI	bSI, BIM Anlægsforum	Ba Nettverket Samferdselsrådet	
Collaboration with international organizations	ISO, CEN[12], CEDR, bSI, EU BIM taskgroup (EC)	buildingSMART, ISO, CEN, OGC, CEDR, UIC Nordic Road and Rail BIM Collaboration group (NBC)	bSI, CEN, ISO, CEDR, OGC Nordic Road and Rail	bSI Nordics, CEN, CEDR, ISO Nordic Road and Rail	ISO/TC-211, OGC, and CEDR INTERLINK[13]	bSI, CEN, ISO, CEDR Nordic Road and Rail
Collaboration platforms within country	BIM Loket, OGF	buildingSMART Finland Infra room	BIM Alliance Sweden	BIM Infra.dk Anlægsforum	Ba Nettverket	CDBB, UK BIM Alliance

Notes: bSI = buildingSMART International; OGC = Open Geospatial Collaboration

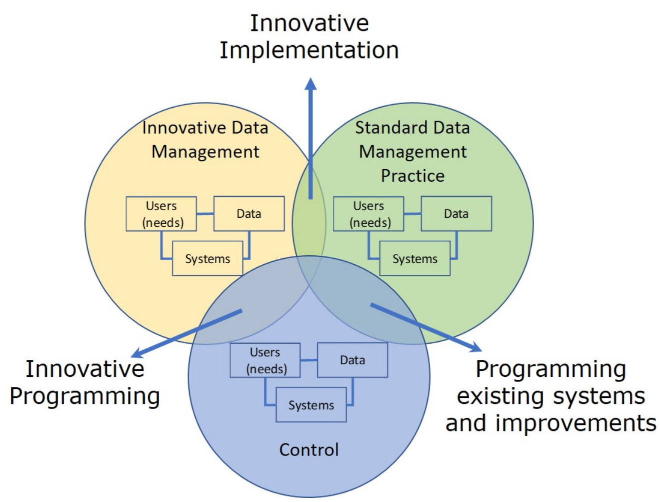
[12] European Committee of Standardization.
[13] INTERLINK, Developing an Open, Scalable and future ready European Road Object Type Library (OTL) for meeting the business needs of CEDR members. https://www.cedr.eu/strategic-plan-tasks/research/cedr-call-2015/call-2015-asset-information-using-bim/interlink/

The collaboration activities of RWS and Denmark InfraBIM.dk are described in the following subsections as representative examples of the extent and attitudes to external collaboration exhibited by the host organizations.

The Netherlands/RWS

RWS, although the largest public procurer, understood very early that advancing BIM requires wider industry collaboration.

Figure 2-9 identifies how innovative data management practices afforded by embracing open BIM concepts work together with existing practices and legacy systems and controls at RWS. The innovative programming and implementation support piloting (for now) and controlled systems and existing practices continue the production work. The hope is that, eventually, the innovative data management and programming and implementation processes will be mainstreamed as improved processes and applications are mainstreamed.



Source: RWS (2019). AIRBIM Program

Figure 2-9. Chart. Collaborations at RWS between standard practices, existing production-level systems of record and their trajectory and new ways for data management through BIM.

According to RWS, organizational change management within RWS to bring about this innovation is a huge challenge. An even greater challenge is related to bring about change in the industry and supply chain involved with the delivery of projects and operations and maintenance services. As part of its march toward FAIR data, RWS recognized very early on that open BIM is the approach to take to achieve data interoperability, sustenance, and data use. But embracing open BIM means putting together data governance structures, developing and achieving "buy in" for acceptable industrywide standards and processes and developing tools/applications to migrate data from one system to the other. To accomplish this, requires stakeholder collaboration. RWS collaborates at three levels:

- Executive-level collaboration
    - Bouw Informatie Raad (Now called Bouw Digitaliseringsraad, ENG: Construction Digitalisation Council) or BIR (Building Information Council)—A driving force behind BIM collaborations in the Netherlands. It is a partnership between owners/clients, contractors,

    engineering firms, utilities companies, and architects and manufacturers/suppliers drawn from multiple sectors (transportation, rail, water) who are making the transition to BIM together. Responsible for creating knowledge, educational products, national models for BIM protocols and BIM execution plans (BEPs), national open BIM standards such as CB-NL (definitions for objects and spaces) and COINS (to facilitate information exchange and develop a combined database of information), etc.
    - OGF or Het Opdrachtgevers (Client Forum in Construction)—A network of public clients who exchange experiences, share and develop knowledge and initiate ideas about new themes in construction and infrastructure.
- Operational-level collaboration
    - BIM Loket—An independent nonprofit foundation for open BIM standards (development and maintenance) founded in 2015. Core stakeholders are large public clients (including BIR), industry associations, and central government from multiple sectors who are a part of the Construction Digitization Council (BDR). BIM Loket is working toward a goal to promote integrated collaboration and innovation around BIM and has a vision to realize a world where BIM and open standards are the norm.
    - CEDR (Conference of European Directors of Road)—RWS collaborates in the knowledge sharing, benchmarking, joint development, and competence building activities of CEDR along with other European Union nations.
    - DigiDealGo—This is an agreement between the Dutch government, the trade associations of the construction industry, the installation sector, and the supply industry to promote digital acceleration in the built environment. RWS participates in the acceleration projects of DigiDealGo aimed at showcasing innovative data management practices.
    - EU funded project V-Con (2012-2017).
- Collaboration around standardization
    - RWS collaborates/initiates/leads at the international level with standards organizations such as ISO, CEN, NEN, and buildingSMART involved in developing BIM standards (e.g., ISO 19650 or IFC Road).

RWS staff who participated in the study tour opined that from a planning standpoint, setting up multi-sector national collaborations should be handled first and foremost. They emphasized the need to invest in national level collaborations to bring together public procurers (from highways and other sectors), contractors, software, and consulting companies. The need for international collaborations was also expressed as an important step to ensure that effort is not duplicated, national voices are heard, and that the standards adopted are in sync with those in other countries so that the market parties understand public client requirements.

It is the general belief of RWS that not a single organization can steer the development and implementation of BIM on its own. Hence (inter)national collaboration with the sector is essential.

Denmark/DRD

Two of the country's largest infrastructure owners, Banedanmark (Rail authority) and the Danish Road Directorate, have entered into a five-year collaboration to work specifically on open BIM standards as part of their efforts toward digital transformation of the Danish infrastructure sector—termed BIM Infra.dk.

DRD places heavy emphasis on international cooperation and international standardization work in the field to avoid "reinventing the wheel" and leverage a wider knowledge base. Examples of such collaborations are as follows:

- DRD is a part of the Nordic Rail and Road Collaboration forum. This forum is comprised of public clients in the linear infrastructure domain from Sweden (Trafikverket), Norway (NPRA, Bane NOR, Nye Veier), and Finland (FTIA). A memorandum of understanding (MOU) signed between these organizations set the terms and understanding to share results and investigate on how to support common Nordic BIM goals on a large international arena. The discussions held in this forum help DRD take calibrated and careful steps towards their own BIM maturity goals. A recent example of collaborative research conducted by this forum is the "Nordic Study of Classification Systems for infrastructure Transportation." An important outcome of this study which is being put into practical use is that:

  > *"There is no specific classification system that can be recommended however the features and aims of CCS & CoClass which combine the requirements of current facet and enumerated standards plus uses reference designation approach defining relationships and aims culminate in asset delivery comes closest to meeting the criteria."*[14]

- DRD is a part of the buildingSMART International chapter and follows the work of the organization in its Infra rooms as it relates to the various information exchange standards and delivery specifications.

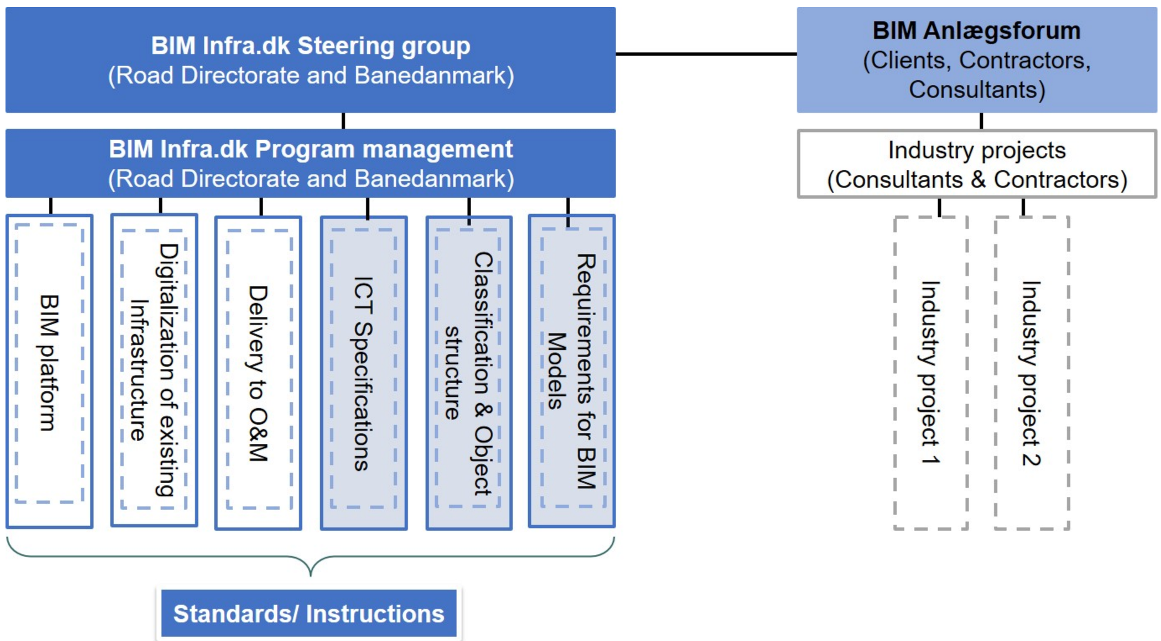
Another point of emphasis of DRD and Banedanmark is collaboration with industry to jointly work on issues and gain wider acceptance for recommendations. Industry involvement is achieved through a common platform called the BIM Anlægsforum, which acts as a consultation and sparring partner for DRD and it rail counterpart Banedanmark. Anlægsforum contributes heavily to the national BIM strategy by progressively working on issues and creating national recommendations. Figure 2-10 presents the structure of the interaction of DRD and Banedanmark (BIM Infra.dk) with BIM Anlægsforum. The figure also shows that while public clients are in charge of steering the overall direction of the standardization and policy recommendations around BIM (e.g., requirements, classification, and object structure), the industry is involved in taking up special projects and working through issues that arise from such standardization and policy considerations and set the direction for implementation. For example, industry input was sought on important topics such as:

- CAD layer structure (to structure data in CAD models). BIM infra.dk is working on building a classification and object structure, but it is estimated that it will continue to make use of the CAD layer structure for a long period of time as an interim information model.
- Requirements for common infrastructure BIM models in design. This effort resulted in an update to the CAD Manual and the publication of a model standard for BIM projects.

[14] Jackson, P., *Nordic Study of Classification Systems for Infrastructure & Transportation*, Version S2, Practical Requirements for Classification of Information in Digital Engineering & BIM, Nordic Road and Rail BIM Coordination.

- ICT specifications on BIM projects. A key product was the definition of specific information and communication technology requirements and conditions that all parties to a construction contract must abide by. These specifications become a part of a contract.

Two types of meetings are held between public clients and industry—three times a year at the decision-making level (consultants and contractors) and regular meetings at the technical expert level as needed. In addition, two user-level meetings are held where everyone is invited to an open dialogue to offer constructive information about the use of BIM in infrastructure.



Source: Vejdirektoratet, Danish Road Directorate (DRD). 2019.

Figure 2-10. Chart. Organization of the public client and industry BIM collaboration in Denmark.

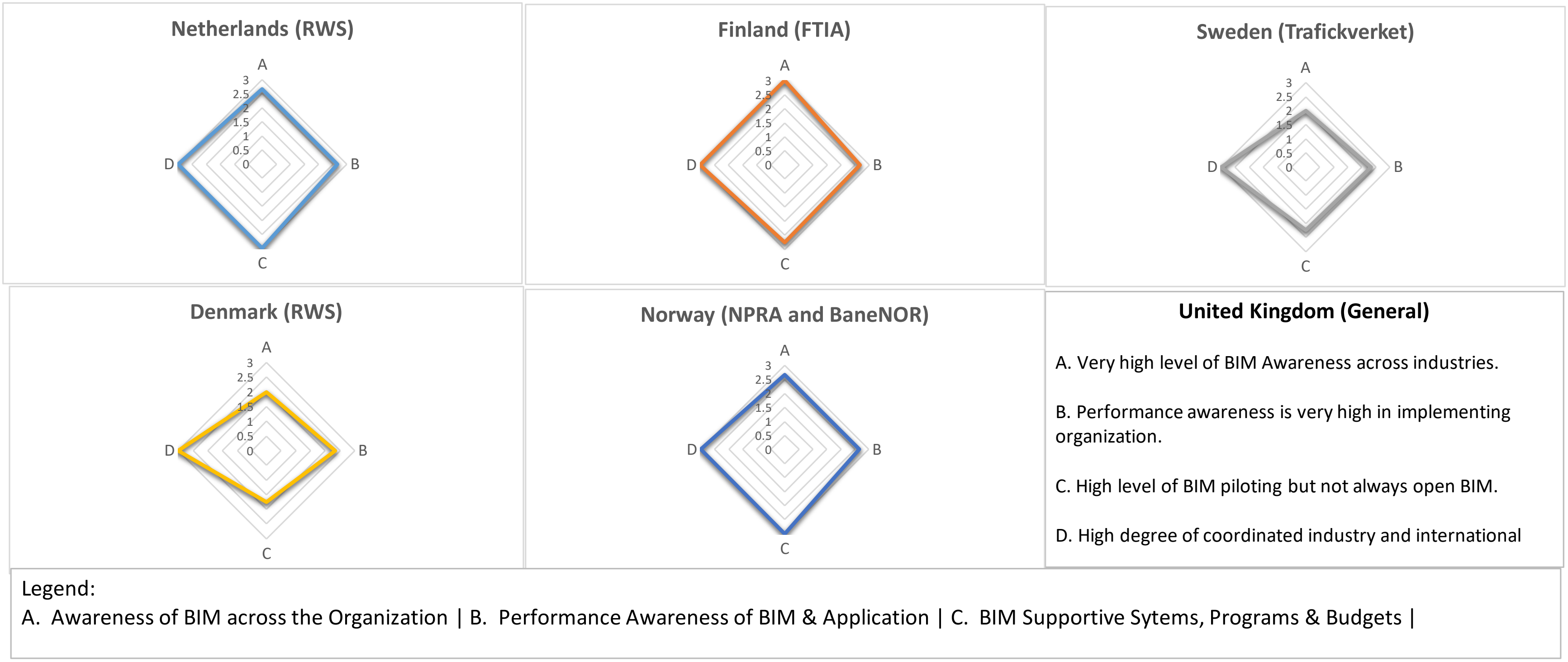
2.6 Summary of Capability Assessment

Figure 2-11 provides a quick comparison of how each BIM-mature host agency interviewed aligned with the critical success factors articulated in table 2-1. Note that the UK, even though a highly BIM-mature country, was not assessed since the capabilities of highway organizations within each country interviewed were specifically assessed. The study tour did not have a chance to visit with the highway agency in the UK and hence this assessment could not be conducted for that agency. However, as can be surmised from the discussion, the UK is a leader in BIM and the study team had a chance to interact with and learn from a range of civil servants, civil infrastructure, and transportation experts from the public and private sectors. The general reflections of the BIM maturity within the UK are included as statements in figure 2-11.

It is to be noted that the capability assessment in figure 2-11 was carried out by the study team based on the evidence gathered during the discussions held during the visits as well as post-study literature obtained from the host organizations. The assessment was carried out to visually summarize the impressions of the study team and is not to be used for any other purpose. The host organizations were not involved with assessment.

In constructing figure 2-11, for every component of each success factor analyzed, agencies were given a numerical score of 1 (lowest possible score) to 3 (highest possible score) depending on the information they shared. All the component scores for a critical success factor were then averaged to represent the score for a given factor. Key observations from the figure are as follows:

- BIM-mature agencies rank highly on the following critical success factors:
    - BIM Awareness
    - External Collaboration
- BIM supportive programs and, specifically, dedicated BIM programs were identified in only three agencies (RWS, FTIA, and NPRA). Consequently, these organizations were involved in several enterprise wide development efforts related to BIM and training efforts. However, even without a dedicated program, Trafikverket and DRD are still were advancing BIM efforts through unit-specific budgets and by capitalizing on the opportunities to pilot BIM on major projects (e.g., the E4 Stockholm Bypass Project).
- Creating broader performance awareness, BIM systems, supportive staff, and budgets were noted as consistent challenges among these organizations.
- Overall, although all the host organizations visited were highly advanced BIM practitioners, among them RWS, FTIA, and NPRA seem to have a structured approach and are further along in their development, piloting, and mainstreaming efforts. But the others are not far behind.



Source: Original. Created by Authors.

Figure 2-11. Illustration. Perceived maturity of the various host organizations in relation to organizational readiness and capability to succeed in BIM implementation.

Note: The ratings presented above are based on the findings and discussions at the time of the interview. All countries are making improvements to their respective BIM programs and therefore these ratings may change with time. For example, Denmark was in the process of creating a wide BIM foundation at the time of creation of this report. This foundation involves advancing BIM through pilot projects. A test model concept is being finalized and templates are being developed as part of that initiative.

3. Building Blocks of BIM for Infrastructure

CHAPTER SUMMARY

- The building blocks of BIM for infrastructure include: (1) information requirements for data models; (2) standards used for creating models characterized by classification system, ontologies, and object-type libraries (OTL); and (3) BIM processes that involve using the model as contract document, and for capturing asset data, clash detection, and quantity takeoffs.
- Information requirements should be established considering the information needs of multiple stakeholders within the organization and the external stakeholder community. International information management standards such as PAS1192/ISO19650 should be used to establish the framework and process for documenting and maintaining the Organization, Asset, Project, and employer information requirements (i.e., OIRs, AIRs, PIRs, and EIRs)
- There are many in place and emerging international standards and their national adaptations that can be leveraged by the U.S. highways agencies to mature information modeling practices. These include areas such as classification of roadway assets, establishing asset object libraries (e.g., using OGC, ISO, and buildingSMART standards such as IFC, GML, CityGML, InfraGML, and ISO/TC-211), developing open BIM data schema or ontologies, and linking data. In addition to the information modeling standards, data management and exchange standards and processes such as the ones documented in buildingSMART's Information Delivery Manual (IDM), should be defined. Establishing process standards should involve defining information exchange and processing standards such as COBie (Construction Operations Building Information Exchange).
- Most agencies visited on the GBP study tour suggested working collaboratively with multiple stakeholders nationally and internationally to address the building blocks. Identifying and adopting open standards, building on open standards to develop a national OTL, and ensuring interoperability between models created using different OTLs are topics that need discussion.
- Mature BIM organizations are spending the time and energy necessary to restructuring data and information modeling practices that break down data "silos," promote data interoperability, and automate work tasks. It is a deliberate and time-consuming task but is considered essential.
- Most agencies are applying the newly developed requirements and information models and associated tools to practice BIM workflows in the design-construct stages of major projects leading up to as-built asset information handoffs. BIM workflows being deployed include: use of a model as a contract document, and model use for visualization, clash detection, quantity takeoff calculations, storing asset data, automated machine guidance, and contractor payments.

3.1 Introduction

The work to mature asset information management to support BIM for infrastructure in organizations requires developing a common understanding at the organization level around the following questions:

- What information regarding assets needs to be collected to satisfy the various needs of an organization's internal stakeholders (e.g., planning and engineering, financial, risk departments) and the interacting external parties (e.g., legislators, regulators, general public)?
- How should the assets be organized or classified within the various project and asset information management systems of an organization such that the information pertaining to them can be stored, exchanged, and used to serve the various information needs of stakeholders at various stages of the project's life cycle? What business processes and data standards should be adopted to ensure consistent capture, storage, exchange, and validation of asset information throughout the asset's life to harness its potential value?

> ❖ An **object** is described with its object-type data, geometry data, and metadata. Metadata are data (or information) about the data of objects. Metadata are needed because each object type has its own properties.
>
> ❖ How the object types are grouped is called an **ontology**. The object type library (OTL) can be linked to a data dictionary with the definitions of object-types.

Many of the European public client organizations that were interviewed as part of this GBP benchmarking exercise have embarked on a systematic path to address these questions. They are all convinced that BIM is an enabler to unlock the potential of data and an impressive array of benefits. They also realize that to achieve the benefits requires redesigning the way they define assets and related terms, classify assets in various information systems, and model data and information. From the conversations, the following general steps were considered as building blocks to advancing BIM for infrastructure:

1. Define data and information requirements at each stage of the asset life cycle and map the data requirements to the key information needs (e.g., reporting, decision-support) at that stage. Needs should be viewed holistically from a multi-stakeholder viewpoint—not just by the planning and engineering staff at the organization concerned with the assets but also by regulators, legislators, and members of the public that interact with the client organizations.

2. Create or, if available, adopt a standard classification system for organizing assets. A particularly useful concept here is "object"-oriented approaches to modeling asset information (for example, using 2D or 3D objects in a GIS or design tool to digitally represent an asset or an asset subsystem in the real world, e.g., a column, a wall, a road layer). Establishing the classification system should lead into identification and definition of standard objects that represent the infrastructure elements. An object can have properties, which can be both geometric (spatial) or non-geometric (non-spatial). The geometric properties can represent 2D or 3D location of the object in the physical world using one of

the geographic/spatial referencing standards or linear location of the object using a linear referencing method. The non-geometric properties of an object (e.g., ID, name, material type, structure type etc.) represent the physical characteristics of the object. Additionally, an object can be associated with methods or functions that illustrate what an object can be used to do. For example, a 'bridge' object may have functions associated with carrying load/traffic, connecting two roads, holding pavement, shoulders, guardrails, and other roadway features, etc.

3. This information about objects, object relationships, properties, and methods can be represented using a variety of modeling languages/specifications, in UML[15] Class Diagrams (wherein the objects are representing using classes) and/or Object/Entity Diagrams. These modeling specifications differ in the amount of information (aka, metadata) they can hold about the object. For example, a class diagram can hold information about the methods/functions, but an object diagram is typically used for holding information about objects, object relationships, and properties. In fact, different types of object diagrams, namely, the conceptual, logical, and physical modeling specification diagrams can be used to represent varying degrees of metadata associated with the objects. The modeling specification languages that are used to document information about the object types/classes is an important aspect, particularly from the point of view of enabling data exchange between different enterprise data models and data systems. These metadata specification languages and tools should be used to build the object type library, data dictionaries, and for establishing object groups (ontologies).

4. Object-oriented approaches allow "intelligence" (metadata) to be attached to objects to help relate them to other objects and query and group all related objects for a specific analysis using database approaches—a powerful concept. Establishing open-standard(s)-based OTLs and the associated data schema (or ontologies) that can be used to group the object types according to the classification system is another powerful concept.

5. The focus should be on establishing the standard object types, which are used to represent the transportation infrastructure elements (features), given the variation in their definition and use across transportation agencies in a country. Establishing standard objects (or classes), properties, and relationships is one of the key building blocks needed for creating data models for infrastructure elements. In addition to identifying and standardizing the objects/classes that are used in an agency/country, the standards and practices associated with (1) identifying the information requirements that lead to objects identification and definition and (2) the establishment of information exchange processes are deployed to ensure that the data stored in the data models created using these objects/classes in the different enterprise systems is exchanged seamlessly.

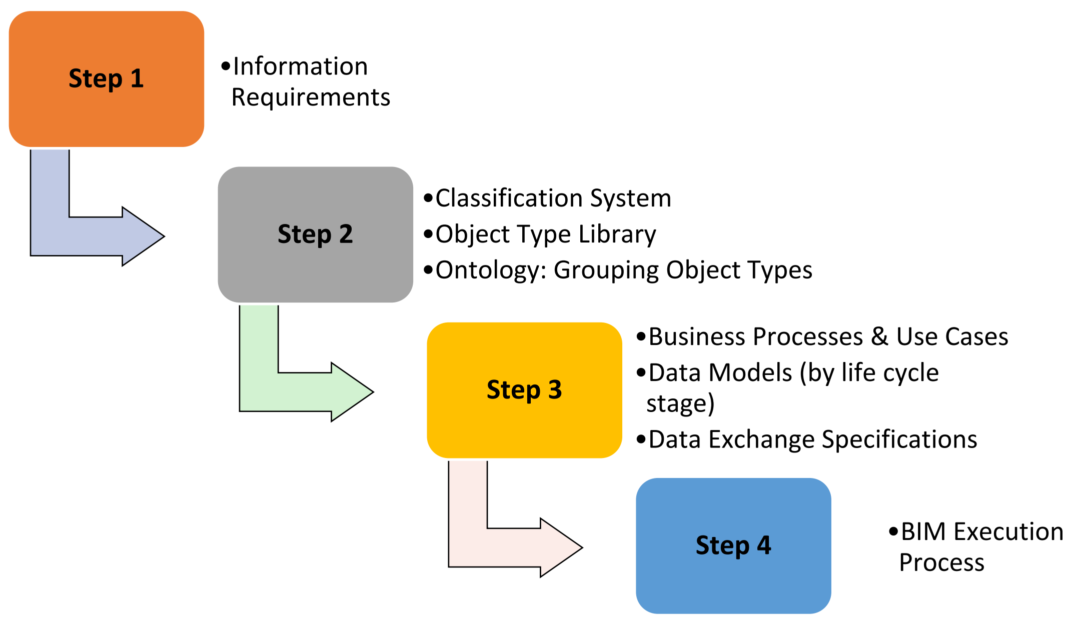
6. Develop BIM business processes that clearly establish the data modeling and exchange practices that should be followed at each stage of the asset life cycle. The object-oriented data models and the data

[15] UML is one of the languages that can be used for model specification and documentation of the standard classes/objects that are used at an agency to represent the transportation features and their properties. A UML Class diagram shows what classes/objects are presented in the data modeling system and what they are capable of doing. The classes may not always map 1:1 to the objects. A UML class diagram can show more information about the objects (e.g., the methods, abstract classes), as opposed to an object diagram that shows the list of objects and the connections between them. The object and class diagrams can be deduced from each other.

exchange templates, views of the data model for various stakeholder use cases (also called model view definitions), and information delivery specifications (IDS) should be developed as part of these processes. The goal should be to establish standard processes for data and information management by delineating each "step" in the engineering life cycle of a facility where data are created, extracted from, exchanged with, generated for, or input in a database (model) for an intended purpose.

7. Once the information requirements, object definitions, data modeling, and management processes have been established, the focus shifts to execution. BIM execution involves building the different data models at each stage of the asset lifecycle using one or more enterprise data systems, followed by exchanging these data models using the developed information exchange specifications.

Figure 3-1 graphically depicts these four building blocks for advancing BIM for infrastructure.



Source: Original. Created by Authors.

Figure 3-1. Illustration. Building blocks to advance BIM for Infrastructure.

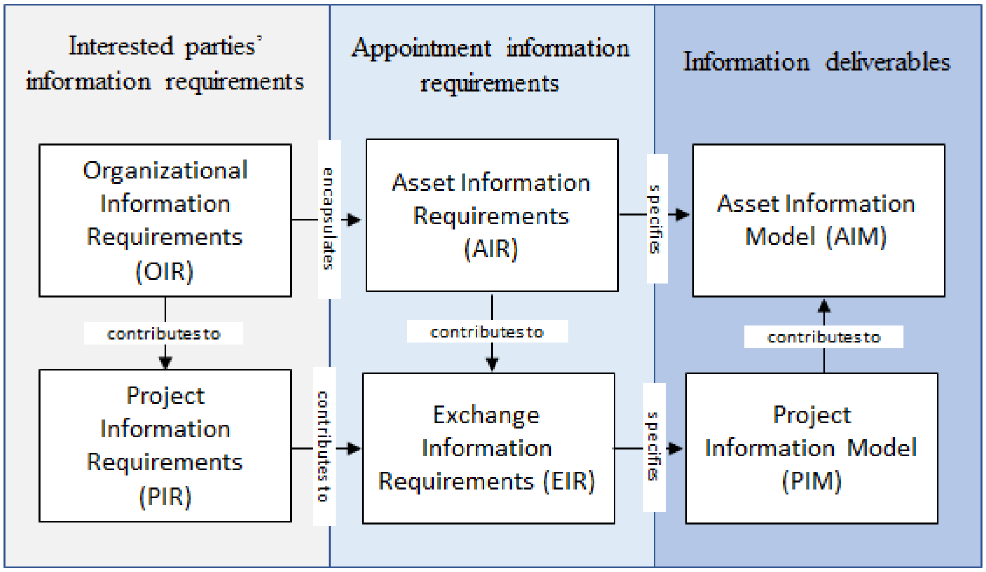
Subsequent sections in this chapter discuss each of these data and information management activities in detail. The lessons that the U.S. could learn from the GBP study that was conducted as part of this research are summarized at the end of this chapter.

3.2 Information Requirements

This section describes how the organizations visited are using information exchange requirements as a foundational element to embark on their BIM journey across every asset of the life-cycle phase, e.g., planning, design, construction, asset management, and O&M. As a first step in building an information management framework, it is important to understand what information needs to be managed. Information requirements defined from multiple stakeholder perspectives (e.g., those providing for, regulating, or using an asset) have a greater chance of leveraging the true power of BIM. Some key stakeholder information needs are defined below.

> ❖ **Public client requirements** are an essential starting step to catalyze industry action and interest (especially among contractors and software vendors).

- **Owner agency or organization** that is responsible and accountable for ensuring (1) the health of the transportation infrastructure; (2) the safety and security of the infrastructure, (3) its data and users; (4) the mobility of people, goods, and services; and (5) the transparent and fair day-to-day business operations. To address these needs, Organizational Information Requirements (OIRs) must be defined. The OIRs convey information required by the organization for project management, asset management and other organizational functions from internal and external stakeholders.
- **Project or contract** that has been created by the owner agency to build and maintain the transportation infrastructure through employment of consultants and contractors who provide the requested infrastructure design and construction services. To address these needs, project and exchange information requirements (PIRs and EIRs) must be defined. The OIRs are used to create PIRs, which are then used to create EIRs (as shown in figure 3-2). The EIRs established by the owner agency set expectations about the data modeling and exchange requirements for the contractors who are involved at various project stages. These requirements convey the employer's information needs and have been developed based on the OIRs. They are project specific.
- **Asset infrastructure** that is being built by the owner agency in collaboration with industry consultants and contractors, so that it can be handed over to O&M personnel (in-house or consultants) to manage the asset throughout its life cycle. Asset information requirements (AIRs) are defined to address asset management needs.



Source: buildingSMART Norway.

Figure 3-2. Chart. Types of information requirements and information models from ISO 19650.

The countries interviewed as part of this GBP study recognized the importance of developing these information requirements. Table 3-1 summarizes the state of information requirements demonstrated through the organizational information and/or project examples shared by the host country organizations. In **Norway, at NPRA,** ISO-19650 and the various information requirement acronyms that come with it (as shown in figure 3-2) are not used. NPRA believes that these terms introduce additional complexity. Instead, the focus should simply be on defining the needs of a data owner and road-owner. NPRA specifies standard deliverables and creates tender templates wherein, the ask is for objects structured in a certain way with properties like 3D-geometry and other information instead of drawings. The models that are created/requested vary across projects. For example, not every project needs a bridge/bridge-model. Level of detail in each model type varies with project phase. NPRA does not ask for set-out data in conceptual design or as-built data (i.e., as planned data controlled against/updated with contractors survey data of built situation/object).

The data models created during each project are used for updating the asset information database (NVDB). The operations/maintenance systems that still require drawings are updated later in the process. Road network data is also part of the deliverables to NVDB, made first as design data—and if nothing changes (seldom does), design data are used to update road network for navigation/route planning, etc. Overall, this process does not require creation of information requirements, as the models themselves serve as the requirements document. NPRA follows this approach to reduce the complexity in their BIM process and avoid use of additional acronyms and formal information requirement documents/templates. In other words, NPRA creates the various Asset and Project Information Models, depending on the type of project, without formally establishing ISO-19650 recommending OIRs, AIRs, PIRs, and EIRs. In concept, the UML models created from the data systems (e.g., NPRAs asset information database, NVDB) represent these data owner and road/asset owner requirements.

Table 3-1. State of information requirements defined for BIM (as evidenced by the information presented or project examples shared by the host countries).

ID	Type of Information Requirement	Norway*	Denmark	Finland	Sweden	The Netherlands	United Kingdom
1	Organization Information Requirements Defined	✓	✓	✓	N/A	N/A	✓
2	Project Information Requirements Defined	✓	✓	✓	✓	✓	✓
3	Asset Information Requirements Defined	✓	N/A	✓	N/A	✓	✓
4	Exchange Information Requirements Defined	✓	✓	✓	N/A	N/A	N/A

N/A: Information is not available.
*NPRA does not formally recognize these ISO-19650 requirements. But in concept, the data owner and road/asset owner requirements are reflected in the UML-based Project and Asset Information Models, which are created based on the information required in the asset information database (i.e., the NVDB).

In the **UK,** the UK BIM Alliance has produced comprehensive guidance[16] on establishing a construction project's information requirements, and how this information should be procured, produced (including roles of the various actors), stored, and handed off to the various supply chain actors. The guidance is to be read in conjunction with ISO 19650-2. Although this guidance is focused on information delivery aspects during construction projects (or on aspects of PIR), the UK BIM Framework and ISO 19650-2 relate the PIRs and activities to OIRs and AIRs. The requirement development process is iterative and starts with defining the key decisions that need to be made at each stage of the project and establishing the information required to make these decisions. The level of detail required in the requirements document is described by the Appointing Party (owner or owner's representative). Ultimately, the importance of the owner transportation agency defining asset information requirements for primary and secondary assets at the component level is recognized by both the public client organization and all the market partners, i.e., contractors, consultants, subcontractors, etc.)). All parties must agree to identify the

[16] Information management according to BS EN ISO 19650 Guidance Part 2: Processes for Project Delivery Published by the UK BIM Framework (Edition 3). https://www.ukbimalliance.org/wp-content/uploads/2020/02/ISO_19650_Guidance_Part_2_Processes_for_Project_Delivery_ThirdEdition.pdf (accessed March 30, 2020).

asset data attributes that should be collected at each project stage and establish requirements associated with the format in which data will be delivered, the collaboration process, and storage mechanism.

In **Denmark**, BaneDanmark manages information requirements for bridges and buildings to comply with the national Executive Order BEK 118. Denmark has created a program for information management that focuses on documentation of requirements, including creation of a digital model, for BIM models. For example, the requirements associated with creating a digital model for construction have been documented.[17] The ICT unit created three documents that form the paradigm for the requirements and capture the basis and requirements associated with information management, the technical communication specifications, and the CAD model requirements. These information requirements are being communicated to construction contractors. DRD has created a tool (model standard[18]) that explains how suppliers need to deliver data. This tool describes the content needed in a model at different levels of development. The requirements serve as EIR for construction contractors to create and deliver 3D models. The amount of information in the model varies by project type.

In the **Netherlands**, information requirements were created from the analysis of business processes. Figure 3-3 shows the business process diagram that RWS used to define AIRs for BIM, i.e., AIRBIM. Business process diagrams show the functional roles and process workflow that are critical for systematically capturing requirements. The AIRs allow RWS to integrate asset management with design and construction. Data exchange processes have been standardized, and information that needs to be received back from the contractor has been clearly outlined. RWS has also had discussions with contractors on the structure of the data that needs to be sent back at the end of a construction project. In addition to capturing the explicit needs of asset management systems, the information requirements also capture the implicit needs of RWS employees. The information requirements were derived by reverse engineering legacy information systems (e.g., asset management system) and established for different types of projects—newly built projects (also referred to design and construct or D&C), maintenance projects, e.g., re-asphalting or bridge deck maintenance (also referred to as engineering and construct or E&C), and design-build-finance-maintain (DBFM) projects.

In **Finland**, FTIA created EIRs that state that contractors must submit as-built asset data models after construction. Guidelines on how the data models should be delivered have also been established. This requirement is not followed consistently across all projects. In addition to the EIR, FTIA developed a road asset information register and established metadata specifications for data and files.

Sweden is currently working on establishing information requirements for digital data models. Contractors have been provided some details of data that needs to be provided after construction and information about file formats that should be used. However, more work needs to be done to establish information requirements.

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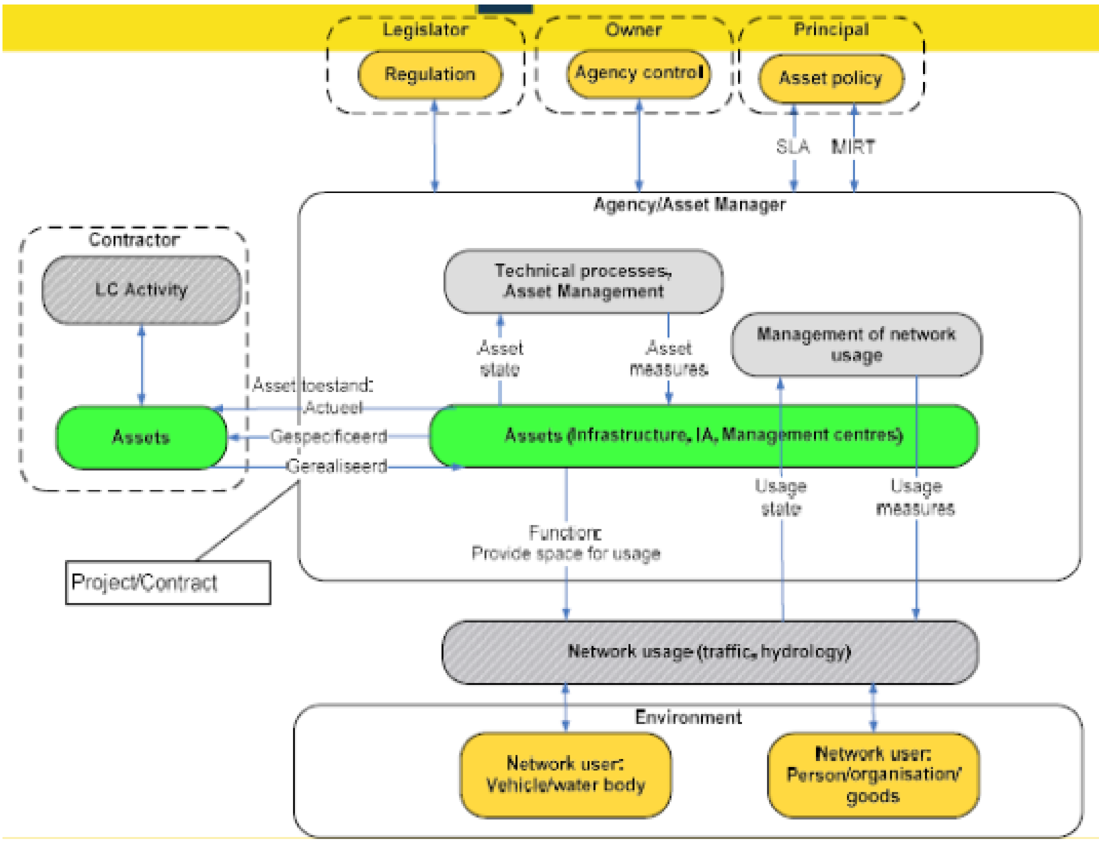
[17] Model Requirements. https://biminfra.dk/wp-content/uploads/2018/08/B3-Digitale-Krav-Og-Aftale-Paradigme.pdf
[18] Danish Model Requirements for Suppliers http://digitalvej.vejdirektoratet.dk/Modelstandard/Sider/default.aspx



Source: Rijkswaterstaat

Figure 3-3. Chart. RWS uses business process steps to establish asset information requirements.

3.3 Classification Systems, Object-Type Library, and Ontology

This section explains how various public organizations in the countries visited are embracing consistent asset terms and definitions across their enterprises/domains/countries. The overview covers the classification systems and object-based data modeling techniques being used to advance BIM across an asset's life cycle. Furthermore, examples from countries that are using foundational "open BIM" (as opposed to proprietary) tools to help "liberate data" from "vendor lock-ins" or "proprietary information silos" and advance reliable archiving, are presented. The use of IFC, LandXML, GML, and ISO standards in relation to this concept is also discussed. Table 3-2 summarizes the classification systems, OTLs, and ontologies that are in use across various countries. To embrace these open standards, client organizations need to collaborate with supply chain actors (e.g., suppliers, contractors, software vendors), many of whom operate nationally and internationally.

- ❖ A **standardized classification system** for civil infrastructure assets (roads, bridges, tunnels) that is "object"-based and consistently interpreted and used by all asset life-cycle actors is at the core of enabling BIM-based automated data exchange processes. The same classification system used in 3D engineered models should be used in asset management or planning systems.
- ❖ Classification systems should be based on the **functional purpose** of the asset in question.

Table 3-2. Classification systems, object-type libraries, and ontologies used.

ID	Data Modeling Element	Norway	Denmark	Finland	Sweden	The Netherlands	UK	US
1	Classification System	UML, ISO TC-211, SOSI (national standard)	Cuneco (CCS/CCI)	Infra 2010 (infrastructure)/ Talo 2000 (buildings)	BSAB or CoClass[1]	N/A	UniClass	OmniClass
2	Object Type Library and Ontology	UML, ISO TC-211, SOSI (national standard)	N/A	Inframodel and LandXML YIV General Infrastructure Model Requirements	N/A	CB-NL IMGeo CityGML The Netherlands CAD standard RWS OTL	N/A	LandXML

[1]Developed based on ISO 12006-2 and ISO/IEC 81346

3.3.1 Classification System

To navigate the large volume and variety of asset-related data in the BIM framework efficiently, stakeholders need a standard way to classify or structure them. The data classification systems that have been developed for different types of BIM data, users' geographic areas, and scenarios include: UniClass 2015, OmniClass, MasterFormat, UniFormat, CoClass, IFC, Talo 2000, buildingSMART data dictionary, NS3451, and TFM (Norwegian classification system).[19] The **U.S.** developed the OmniClass classification (2018) using guidelines laid out in ISO 12006. The **UK** defined the UniClass 2015 system, which divides data using a hierarchical set of 12 categories.[20] **Ramboll**, a global transportation consultancy company,[21] that provides engineering services to Highways England in the UK, stressed the need to align the data entities and attributes in the asset data dictionary with a "classification system" that has been standardized nationally.

The Nordic countries have developed their national classifiers using ISO 12006-2. Between 2003 and 2007, **Denmark** used the DBK (Dansk Bygge Klassification or Danish Building Classification) system but replaced it with the cuneco classification system (CCS), which consists of two main elements—a classification system and an identification system. The classification part is used to distinguish different types of building elements, while the identification part is used to identify each building element. Denmark, however, is still looking to commit to a classification system for organizing information related to civil infrastructure. **Sweden** replaced its old BSAB classification system in 2016 with BSAB 2.0 or the CoClass[22] system, which was developed based on ISO 12006-2 and ISO/IEC 81346. Basically, all classification systems are multi-table hierarchical systems developed on the basis of ISO 12006-2. The Uniclass and Omniclass systems and the CoClass and CCS systems are considered similar to each other because each pair represents a different classification approach.[23] The Uniclass system covers multiple sectors (buildings, civil, landscape, transport, utilities) but lacks detail when compared to Omniclass, which does not cover so many sectors. The CCS and CoClass systems are easier to understand and based on the three-part reference designation system (RDS) in ISO/IEC 81346. **Finland** has been using the Talo 2000 system since 2008 in building sector and Infra 2010 in infrastructure sector. At NPRA in Norway, the term 'Classification system' is not used explicitly. However, the different data models that should be created and the different objects that should be used to create the data models are identified. For example, in the VU-053 project, taxonomy of how infrastructure elements are grouped was established by defining what objects should be used to create "road model," "bridge model," vegetation model, "tunnel model," "lighting model," etc. In other words, NPRAs object classification system[24] is based on the needs of the individual data models that need to be created and the objects that need to be used to create these models. As with the approach taken by NPRA to skip the formal definition of OIRs, AIRs, EIRs, and PIRs, this approach of not defining a formal classification system allows NPRA to simply

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[19] BIM and Classification. http://www.bimaxon.com/what-is-bim/bim-classification/
[20] UniClass 2015 Classification System. https://www.thenbs.com/our-tools/uniclass-2015
[21] Philpott, Ian. BIM Process Lead, Ramboll. Presentation on *Linear Infrastructure, BIM Enablement. Sept. 19, 2019.*
[22] CoClass, Swedish Classification System. https://coclass.byggtjanst.se/login
[23] Classification. https://www.icis.org/wp-content/uploads/2018/07/2018_Classification-system-comparison.pdf
[24] Norway's Object Classification Data Model.
https://www.google.com/url?q=https%3A%2F%2Fbit.ly%2F3gJgYOG&sa=D&sntz=1&usg=AFQjCNHQfQ9hioianb7actKPH-uYBxwBsQ

focus on developing the data models and classifying the objects based on their use in the models (discussed later in this chapter under 'data modeling.'

3.3.2 Object-Type Library and Ontology

OTL is a taxonomy of well-defined objects and its properties (attributes) plus the relationships between the objects. All together, an OTL provides structure to the data modeled according to the OTL.

The OTLs are used to identify the individual building elements (assets), describe the properties (attributes) of each of the elements, and define the functions that can be performed by the element. The objects in the library are used to create digital information (or BIM) models and represent the physical and functional characteristics of the infrastructure assets. OTLs available to build digital models of the transportation infrastructure have been developed based on both open and proprietary standards. The proprietary standards have primarily been defined by software vendors in the design, construction, and asset management disciplines. The open standards can be further categorized into national or regional standards, international standards, and standards developed by national road agencies (NRAs). For example, table 3-2 presents examples of national and NRA standards being used in Finland, Denmark, Sweden, the Netherlands, UK, and the U.S.

- **FTIA** in Finland and other infrastructure parties (clients, designers, contractors) have created in buildingSMART Finland (bSF) Infra room the Inframodel[25] national data modeling standard based on the LandXML international standard. However, given the emergence of the IFC international standard, FTIA and bSF is currently investigating how to transition from using LandXML to using IFC/GML in Inframodel, as the basis for development. This involves understanding the future role of IFC, GML, and LandXML. Like the U.S., LandXML has widespread use in Finland. It has been handed over to buildingSMART Finland (bSF) for hosting and development; Finland is tracking both LandXML and IFC (used in bridges and buildings).

- In the Netherlands, **RWS** designed multiple OTLs to support the organization's goals and asset management business processes for all three networks (road, rail and water) over the complete life cycle (define, design, build, maintain, dispose) of network and assets. The OTLs also support network operations (i.e., traffic management, water management). On national level a concept library called CB-NL, wherein the standard terms and definitions of the built environment are defined. The terms and definitions in CB-NL have been used to extend OGC's CityGML international data modeling standard to create a national OTL standard called IMGeo. Additionally, the Netherlands uses proprietary data modeling standards from MicroStation and Autodesk (e.g., DGN, DXFs). A "modeling and linking guide" has been created to establish the approach for developing the top level of the ontology that can be used to model data together with the usage and application of the LinkedData languages developed by W3C.

- In addition to establishing national government standards for data modeling, **RWS** has also recognized and leveraged various partner standards such as: ETIM, SALES, IFC, COINS, IMGeo,

[25] Inframodel 4.0. https://buildingsmart.fi/infra/inframodel/

CityGML, NLRS (Dutch Revit), and National BIM Protocol. IMGeo was created by extending CityGML. RWS is currently in the process of migrating from OTL 2.0 to OTL 3.0, which involves probably integrating W3C standards.

- **Highways England** in the UK has published its data dictionary to clearly communicate with all stakeholders and establish the objects, object relationships, and attributes that are recognized and understood across the enterprise systems.

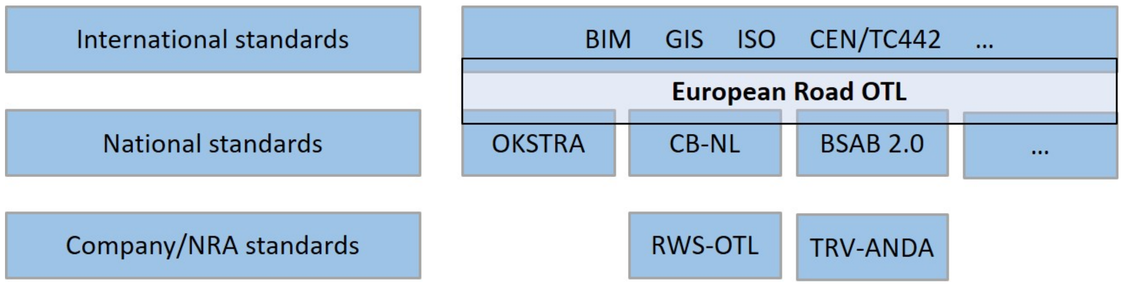
- Sweden's **Trafikverket** aligned the objects used for creating information models in the building industry with the IFC standard and is currently mapping these objects to the CoClass Classification scheme. GML standards are also being used, and the focus is on ensuring a balance between implementing IFC and GML standards.

- **Denmark** created a program for information management. The structure of the program involves creating a "Classification and Object Structure" for digitalization of existing infrastructure and information exchange.

- **NPRA** uses the UML models for identifying and establishing the library of objects[26] that would be used to create the data models. The grouping or ontology of objects is created based on the type of infrastructure data model (e.g. road model, tunnel model, vegetation model etc.) that is created using the objects. The UML models showing the list of objects/classes, properties and relationships are created using Enterprise Architect.

In addition to these national and NRA OTL initiatives, CEDR launched a pan-European initiative called INTERLINK in 2016. The objective of this initiative was to create information management standards for the delivery and operation of infrastructure assets, so that the NRAs and their supply chain (suppliers, contractors, software vendors) have a future proof, 100 percent open and software-agnostic, European Road OTL for data modeling and exchange. The vision for this OTL includes adopting national and international standards from standard development organizations like ISO and CEN, as shown in figure 3-4. Some of the national standards that were taken into consideration in development of the European Road OTL include OKSTRA, CB-NL, RWS-OTL, and BSAB 2.0. While these standards from the Netherlands, Sweden, and Germany were adopted, NPRA (Norway) observed that the Linked data/Semantic Web technology discussed in the INTERLINK project was best suited to connect information to objects, but not to model objects conceptually. For conceptual object modeling and linking information to objects, NPRA found its UML-driven software models better suited.

[26] NPRAs UML Model showing Objects/Classes, Properties and Relationships. https://gml.arkitektum.no/SOSI_Vegkropp/SOSI_Fagmodell_Veg_20200424/index.htm?goto=3:317



Source: https://www.roadotl.eu/faq/?page=2

Figure 3-4. Chart. Position of proposed European Road OTL in the hierarchy of national and international standards.

3.4 BIM Data Processes

This section discusses the key data processes that organizations and businesses representing the study tour host countries have deployed for data and information management on their BIM projects and enterprise efforts. Two processes were specifically covered in greater detail:

- A **project procurement process**, wherein agencies are using model contract templates with clauses that lay out expectations associated with data and information management.
- A **data modeling and exchange process** that is being used to manage data during design-construction and for hand-off as-built asset information to asset management.

During the procurement process, the expectations related to data and information management are laid out formally in the contracts by documenting information about rules, roles, responsibilities, deliverables, processes, and obligations. Once procurement is complete, the data modeling and exchange process ensures successful execution of agreements made during procurement. Planning and execution are key building blocks for information management on any project.

3.4.1 Project Procurement Using Model Contract Templates with BIM Clauses

The process of procuring resources and services for capital and maintenance projects is involved and intricate at most transportation agencies. During this process, it is important to set expectations about data that would be modeled and exchanged between the infrastructure asset owner (typically, the transportation agency) and the service provider (i.e., the contractor). These expectations need to be established for the infrastructure assets that are part of the project; however, the contractual language associated with the data modeling and exchange requirements needs to be consistent across projects. This can be accomplished by using standardized contract templates on each project as a starting point. Such templates would include information that specifies the data services that will be procured (i.e., the data deliverables), roles and responsibilities associated with data management (creation, verification, storage, exchange, etc.), obligations, liabilities, data delivery and payment schedules, costs, and contingencies. The design, development, and use of “model contract templates” on projects would allow owner agencies to set the foundation for information management during the course of the project.

Several European agencies have developed standard contract language and templates that establish data-related expectations.

Table 3-3 summarizes some of the data management related features of the procurement contracts that are being used for BIM projects in Europe. For example:

1. **Models as Contract Documents:** Vejdirektoratet provides models to contractors during procurement. Drawings are still produced, but they are required to be based on the models. The designers make the road model available for bidding (such a model is referred to as a Tender model). Trafikverket also uses models as contract documents. Trafikverket assumes liability for the models. If contractors cite issues, agency consultants fix the issues. This practice was also highlighted by one of the UK presenters representing the Gatwick Airport's Baggage Handling Modernization project.

   In Norway, NPRA provides design data from previous project phase as model data and all other relevant data (reports, survey data, etc.) to the bidders. NPRA particularly emphasizes that the public project owner provides basis data (e.g., aerial scanning, geotechnical, etc.) of best possible (and always documented) quality to bidders to ensure conservation of resources since bidders do not have to gather these data during the bidding process. This gives bidders the best possible information for accurate pricing and to make effective transitions from phase to phase. Currently, NPRA is providing models in both proprietary and open formats to assure that all information is carried through the various project phases. This approach prevents wasteful use of time and resources (e.g., resources utilized for aerial scanning); and ensures effective transition from one project phase to another. In fact, as the project progresses from one phase to another, it is ensured that the specifications for model deliverables are clear. This is accomplished through the use of UML models for documentation, as opposed to text-based handbooks and specification documents. Across all project phases, NPRA encourages use of models as opposed to drawings. They are hoping that when their UML-modeling efforts are completed, all the deliverables will be in open and standardized formats. But until such time, they consider that a mix of open and proprietary formats for deliverables is a pragmatic approach.

2. **Information Modeling and Delivery Requirements:** Trafikverket in Sweden has created templates for contract documents. These templates are being used to standardize the digital information delivery requirements across projects. In the UK, the Construction Industry Council (CIC) has established a BIM protocol (this guidance was further updated in 2020 by the UK BIM Alliance to line up with ISO 19650-2). The CIC BIM protocol requires development of a Model Production and Delivery Table (MPDT), which is considered a contractual document and contains information about: (1) the originator of each model; and (2) the level of detail required in each model, which depends on the project stage at which the model is built. The project stages at which the model should be produced with appropriate detail are aligned with key employer's decision points, which are points where defined information has to be created and exchanged with

the employer.[27] Implementation of the guidance in the UK is varied, but the UK BIM Alliance is striving for more uniformity in this regard. Within RWS in the Netherlands, the IDS is a part of the contract legal document. The requirements associated with transfer of data are specified in the IDS. The presence of IDS in the contract document guarantees a uniform exchange of information about construction work between RWS and the market party. Specifically, ILSs in the contract document allow for establishing agreement related to: the delivery process, the responsibilities of contractor and client in the field of information delivery, the method of transferring the information (COINS), the frequency of transfer, and the (open) standards to be used for data exchange. In Denmark, the specifications for modeling and information exchange have been documented.[28] In Norway, NPRA believes in not creating documentation and templates for capturing information requirements and modeling specifications. Instead, NPRA uses the UML models created from data systems to establish what data is captured and is modeled in each system. NPRA considers these UML specifications as sufficient and rate it as a better approach for establishing information requirements and modeling needs. There is no separate documentation. This approach at NPRA is based on the principle that the focus of BIM should be on implementation, rather than documentation.

Therefore, instead of recognizing ISO-19650 requirements, acronyms, and corresponding templates, NPRA focuses on establishing the data model in its systems by creating the objects/classes and properties, and, using those to develop the UML class diagrams which indicate what data must be captured during a project, or, for an asset in the software system. In other words, NPRA has established a systems-centric approach that focuses on implementation of data requirements in the system to create UML diagrams, rather a specifications development approach that involves developing specifications before using them to update the systems.

3. **Vendor Neutral Data Models**: Within Trafikverket in Sweden, a procurement law has been created to ensure that vendor neutrality is maintained in the use of CAD file formats during BIM projects. In Norway, currently vendor neutrality data models are not created. Every model is delivered in both open and proprietary formats. The proprietary format is never specified, and it is up to the contractor/designer to choose software and format. This practice in Norway is primarily due to the rules associated with competition. NPRA recognizes that the current state is not ideal, and hopes that in the future all deliverables will be on open, standardized data formats. NPRA believes that the UML-based data modeling specifications will be key to establishing the practice of developing vendor-neutral data models.

4. **Data Management in a Common Data Environment (CDE):** Vejdirektoratet in Denmark stipulates the setup and use of a CDE for information exchange during design and construction. In the UK, the UK BIM Alliance follows the ISO 19650-2 view that the Appointing Park (e.g., the project owner) or its representative provides and manages the CDE. The Appointing Party is

[27] UK Construction Industry Council (CIC). BIM Protocol – Model Production and Delivery Table (MPDT). https://www.designingbuildings.co.uk/wiki/Model_production_and_delivery_table_MPDT
[28] Denmark BIM Specifications for Modeling and Information Delivery. http://biminfra.dk/wp-content/uploads/2019/11/BIM-Infra-IKT-specificationer-191110.docx

responsible for managing all information containers that are developed and exchanged with it throughout the life of the project from each delivery team. An important interpretation of the UK BIM Alliance in this regard is that a CDE is not just about technologies or software solutions (e.g., data stores containing electronic document management systems and databases), but rather that it is equally about the workflows within and between life-cycle stages. For example, document management tools for design files, contract management tools that manage commercial information, email management tools for correspondences, and mobile-based tools for site quality data. It can also include workflows related to hardcopy document storage (e.g., postal correspondence).

5. **As-Built Model Delivery Requirements**: Vejdirektoratet in Denmark defines contract delivery specifications to set expectations on how the contracted work should be closed out. Model standards ensure that the data can be procured from contractors. Data needs to be shared and made available to all project participants. Design contractors are required to deliver DGN files. The Directorate does not take responsibility for conversion to other formats. Contracts specify that design contractors are required to create 3D models and meet model verification requirements. In Norway, at NPRA, for as-builts, the contractor is required to update as designed models with changes according to set rules. For example, there are tolerances for locating a light pole using coordinate referencing system (say 5 cm in x, y coordinates; 3 cm in z-elevation). If such tolerances are not met, the contractor has to (a) correct the error, and (b) ask for permission to correct design data. The as-built asset data models are also corrected if the change is required by operations and maintenance unit. Usually the tolerances are 20 cm +/-. So, NPRA expects to get updated models delivered as-builts, which are archived and also used to update the asset management database (NVDB) and the asset information viewer (vegkart.no) used for visualizing NVDB data.

6. **Contractor Payments:** In Finland, FTIA includes a stipulation in some of its contracts that the data models developed by the agency will be compared with the models developed by contractors prior to paying contractors. The comparison involves reviewing quantities. As mentioned above, Denmark also requires contractors to meet the model verification requirements to close out the contract and get paid. In Norway, NPRA uses contractor's documentation (e.g., by survey, scanning, etc.) to pay for quantities, if the quantities claimed exceed a certain threshold level; otherwise, bid estimates are used for payment. For many applications, NPRA specifies Triangulated Irregular Network (TIN)-models from the contractor to document what's being excavated/filled, otherwise survey data by total station, machine control system, etc., is used.

7. **BIM Project Execution**: Within Trafikverket in Sweden, templates for BEPs have been created so that the BEPs associated with the projects can be prepared and reviewed quickly. In the UK, BEPs are driving the standards-based BIM practice. In Denmark, BEPs are being created as part

of pilot projects.[29] In Norway, no BEPs are needed if the contract/tender template specifies BIM deliverables and other procedures.

Table 3-3. Data and information management related features of procurement contracts.

ID	Contract Features	Norway	Denmark	Finland	Sweden	The Netherlands	UK
1	Models to be provided to contractors during procurement (in addition to drawings)	✓	✓	Most cases	✓	ND	ND
2	Specifications on digital information modeling and delivery requirements (e.g., model delivery schedule)	✓	✓	✓	✓	✓	✓
3	Vendor neutrality maintained in development of CAD data models (i.e., open standards based, non-proprietary data models)	No	ND	✓	✓	ND	ND
4	CDE be used as the information exchange platform	✓	✓	Some cases	ND	ND	✓
5	As-built infrastructure data model submitted by contractors in specified format (owner agency not responsible for data transformations)	✓	✓	✓	ND	ND	ND
6	Contractor payments are made after the as-built data model is submitted, verified, and accepted		✓	✓	ND	ND	ND
7	BIM project execution using BEPs	✓ (1)	✓	Most cases	✓	ND	✓

ND: Information is not demonstrated.

[29] Denmark BIM Execution Plans Use on Pilot Projects. http://biminfra.dk/wp-content/uploads/2020/09/BIMinfra-BIM-uses-sep-20.pdf.

In Norway, the contract/tender template specifies deliverables and other procedures for a BIM project's execution, which are self-sufficient. They do not use BEPs.

3.4.2 Data Modeling and Exchange Process

This section discusses the features of the data modeling and exchange process that are being used on BIM projects during design, construction, and hand-off of as-built information to asset management. In BIM projects, special emphasis is given to the use of open standards-based classification system, OTL, and ontology to build and exchange the data models. When models are built using an object-oriented approach, they can easily be used for: (1) asset attribute storage; (2) clash detection; (3) visualization; (4) quantity take-off calculations; (5) fabrication; (6) automated machine guidance; and (7) as-built information handoff to asset management. Table 3-4 summarizes how transportation agencies in some of the European countries are developing, using, and exchanging data models for design, construction, and asset management handoff.

Table 3-4. Features of data modeling and exchange process used during BIM projects.

ID	Data Modeling and Exchange Process	Norway	Denmark	Finland	Sweden	The Netherlands	UK
1	Data models built using open standards-based object library, classification and ontology	ND	ND	✓	N/A	✓	N/A
2	Design models address asset information requirements by incorporating asset attributes	✓	N/A	✓	N/A	✓	ND
3	Design models used for clash detection	✓	✓	Most cases	✓	ND	ND
4	Design models used for visualization	✓	✓	Some cases	✓	ND	ND
5	Design models used for quantity take-off calculations	✓	✓	Some cases	ND	ND	ND
6	Design models created to support fabrication of asset components (e.g., streel bridge elements)	✓	✓	ND	ND	ND	ND
7	Design models used for Automated Machine Guidance	✓	✓	✓	ND	ND	ND
8	As-built asset infrastructure data models are handed-off to Asset Management Systems for asset O&M	✓	✓	ND	ND	✓	ND

ND: Not demonstrated.

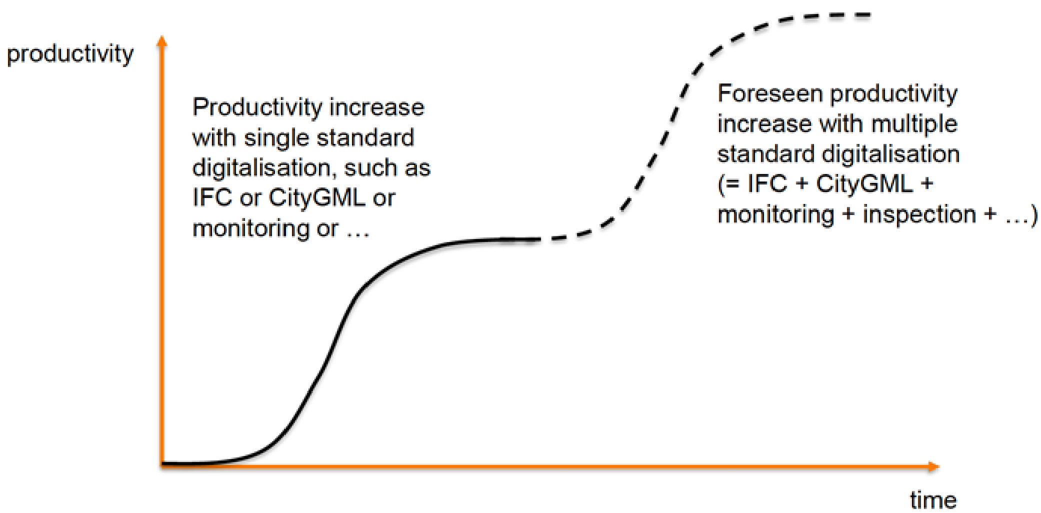
Some examples of how data models are being created and used on BIM projects for information analysis, presentation, and exchange are presented below:

- **Open Information Exchange Standards:** RWS in ***the Netherlands*** has made significant advancements over the years in the adoption and use of open standards for building information models. As shown in table 3-2, RWS adopted open standards and leveraged them to build multiple national standards for data modeling and exchange. RWS believes that a multi-standard approach has to be taken to maximize productivity. Open standards such as IFC, ifcOWL, and CityGML have to be linked and fused together to achieve a whole new level of productivity. Productivity gains by adopting multiple open standards in the information management framework (BIM) can be more significant (as illustrated in figure 3-5) compared to adopting single modeling standards (i.e., just IFC or just CityGML).

  RWS developed the requirements for creating data models by reverse engineering the information requirements from various systems. This resulted in a monolithic data model that need to be later made modular, so that a "model view mechanism" is in place that allows users (e.g., designers, contractors, asset managers) to identify the information needed at any given stage. The current RWS OTL system provides six model views. In fact, RWS does not rely on using a single open or proprietary OTL for all data modeling and exchanges in the enterprise. Depending on the life-cycle stage and process, different standards are used. For example, to classify data objects at a high-level, RWS uses GB-CAS. For defining the concepts and terms, the CB-NL concept library aims to be an industry/sector standard in the future. The Netherlands CAD Standard (NLCS) is used for creating and exchanging object-oriented 3D drawings. Over the years, RWS has realized that there is no "mother of all models." The models created at each stage of the asset life cycle can use different OTLs, each of which should be allowed to be autonomous. However, one should be able to link these autonomous OTLs and the data models created using them. Therefore, RWS has been looking to change the way data models have been created in the past, by allowing the creation of models using any of the open or proprietary open standards, as long as these models can be linked with each other. This ideology is paving the way for RWS to migrate to use of linked data models, which is a step further than using object data models. The focus is on using W3C standards-based linked data models for information management. However, one chain of thought in the Netherlands is that linked data models are more useful in the asset management and O&M phase, as opposed to in the project delivery phase.

  NPRA is using multiple open and proprietary modeling and exchange standards because there is currently no open format that can be used for all design data. Standards such as IFC and CityGML can also not meet these open data modeling specifications. NPRA believes that the focus should be on moving from drawing-based designs, to object-based data models, even if they are proprietary data models. Agencies should focus on establishing the production line for models (built using any available open and proprietary standards).

- **Addressing AIRs**: FTIA in ***Finland*** has established a process for creating the initial data model using the "documented infrastructure modeling requirements" and "data classification/library" or Inframodel/LandXML data standard. It subscribes to the view that perhaps multiple standards may be needed to manage asset information over the life cycle to include both IFC and GML. NPRA puts in a lot of effort in developing high quality data models that can be used to reflect existing situation. Developing such models is prioritized to avoid unforeseen costs in the future. To accomplish this NPRA has identified the key requirements for the data models, such as the need to capture accurate representation of terrain, geology, natural hazards, nature/ecology, pollution, housings, etc.



Source: Rijkswaterstaat, TNO

Figure 3-5. Chart. Productivity gains by adoption of multiple open standards for data modeling and exchange.

- **Clash Detection:** Establishing clash detection involves defining rules that describe:
    - What clash detections are, what are the tolerances that should be controlled?
    - How detailed the visualization needs to be and what purposes would it get used for?
    - What quantities, what rules for calculations? It's easy to count light poles, but excavated masses can be calculated/modeled in different ways.
    - The model geometry requirements for fabrication (prefabrication).
    - The asset information requirements of GIS-systems wherein design data will be imported/exported from/to.

Trafikverket in ***Sweden*** takes a very architectural approach to developing the models. The data models are created to ensure collaboration and coordination between resources. Design data models allow for conflict detection between construction components. BIM Collaboration Format is used for tracking issues in models and associating them with the model objects. Vejdirektoratet in ***Denmark*** also uses its models for clash detection. In ***Norway***, NPRA uses clash detection like Sweden and Denmark. The automation rules for clash detection are specified in the UML models.

- **Visualization:** Within Trafikverket in ***Sweden***, 3D digital data models and databases are used to collect and visualize large volumes of data. The models drive project planning through visualization. In ***Denmark***, BIM data modeling and exchange processes are limited to the design and construction phases. 3D building objects are created for visualization. In Norway, NPRA has established deliverables for visualization. During design, standard CAD models are used for presentation. Animations and/or still pictures are created from the CAD models for standard tender procurements. High resolution/detailed presentations are created from CAD models when it is important to describe the project to public and/or to decision makers. The visualization presentations are created based on specifications in V770 and other handbooks. These presentations[30] are a standard way of presenting model-based road projects at NPRA.

- **Quantity Take-off Calculations:** In ***Denmark and Norway***, Vejdirektoratet and NPRA use design models for quantity take-off calculations. NPRA believes that this is one of the main benefits of created models (as opposed to drawings) during the design phase.

- **Fabrication:** In ***Denmark and Norway***, Vejdirektoratet and NPRA are using design models for fabricating steel bridge elements.

- **Automated Machine Guidance:** In ***Denmark***, Vejdirektoratet is using design models for automated machine guidance. In ***Norway***, at NPRA, machine guidance data models are in high demand. These models are considered special deliverables. The machine guidance systems require models with simple geometry instead of solid objects that are typically used in CAD data models. For example, a triangulated irregular network (TIN) data model would be needed for machine guidance, as it is using simple 2D- and 3D-geometry features such as points, polylines, and polygons. Such geometry is produced late in the design process at NPRA, or by the contractors (if NPRA requests in contract).

- **Asset Management Handoff:** In ***Denmark***, although data from design and construction data model is planned to be handed off to asset management in the future, this is not a current practice. However, in ***Norway***, this handoff of as-builts from design/construction to asset management is an established practice.

3.5 Summary

At a time when transportation agencies in the U.S. are embarking on a journey that involves the pursuit of more efficient data and information management techniques, the lessons learned from the study tour become even more important. The FHWA-led U.S. delegation learned that:

1. BIM is not just about building design or 3D models, although they are logical starting points. The critical interest is in assets and asset related information. It is important to start with the end product (i.e., assets information) in mind. OIR/AIR have to be created first. For this, the list of assets should be developed followed by asset requirements for design/construction contractors.

[30] NPRA Project Model Visualizations. https://www.youtube.com/watch?v=trwd3AhJJB0&feature=youtu.be

Several agencies are not focused on defining BIM. Rather, the focus is on what needs to be accomplished. If the goal is to reduce site errors, the agency focuses on preparing quality data, 3D models, and better flow of data through the various asset life cycle phases.

2. Standard terms, classification systems, and object libraries must be developed based on open standards. Having said that, until such open standards are available, agencies should use (and extend) any available open and proprietary standards to standardize terminology, taxonomies, ontologies, objects, and properties. This will allow agencies to benefit from standardization and from development of data models (instead of drawings). Once such a model-based production line is established, information will flow efficiently across all project delivery phases (planning, survey, design, and construction).Ultimately, the goal is to extend the use of design and construction data and information management standards and techniques to O&M-related business functions. Later, as new and modern open standards become available, agencies can evaluate and adopt them for use in an established model-based data exchange and delivery system.

3. International agencies are looking to adopt multiple OTL standards to support all asset life-cycle phases. For the design and construction phase and for the information handoff to asset management, most of the interviewed agencies are looking at using IFC; however, they are awaiting the candidate standards to launch their evaluations. A notable exception is NPRA in Norway, which is not looking at EXPRESS/IFC for data modeling/exchange. NPRA is not waiting for availability of open standards (including IFC) and, as mentioned earlier, is ensuring that the data from design and construction phases can be made available for use in operations and maintenance phase, using any available open or proprietary standards. Germany has summarized reasons[31] for not waiting for IFC to establish the model-based production line, and agencies such as NPRA not only agree, but have also established additional reasons for moving forward without waiting for open standards to be available. In fact, NPRA is not even focusing on establishing formal requirements templates (as per ISO-19650). Instead, the agency is implementing the data properties that are needed in its software systems, and creating UML models to establish what data is needed in these systems. In general, across all countries the sentiment is to use any and all available international open/proprietary standards and adopt them for use in national and regional domains and disciplines as appropriate. The Netherlands is going a step further in this regard by looking at the possibility of using ontology web language (OWL), following principles laid down in standards which are currently under development. Agencies using LandXML or have developed their own standards (e.g., FTIA's InfraModel), are particularly keen on working out a way to migrate to IFC. Efforts are now being made to evaluate the recent versions of IFC (i.e., IFC 4.1, IFC 4.2) that can be used to create BIM models for highway infrastructure (roads and bridges). In addition to standards like IFC and its derivatives (e.g., ifcOWL), some of the other data modeling standards that have emerged on the radar of European agencies include OGC standards like InfraGML and CityGML. The use and application of graph data modeling

[31] Germany. Evaluation of Data Modeling and Exchange Standards. https://drive.google.com/file/d/17vajYmF7wrZfM065MTVEMc5y9kBxrlnQ/view

standards such as Resource Description Framework (RDF) and its derivatives (e.g., RDF-a) are also being pursued, primarily for automated computation of data entity relationships through analysis of existing relationships (a graph data modeling concept that enables smarter data processing, integration, and analytics, when compared to relational data modeling techniques). Agencies are using the open standard based OTLs for creating BIM models and exchanging data during projects. The open standards have been enhanced to include agency-specific data entities (objects) and attributes that align with agency-defined data terms and definitions.

In summary, the GBP study revealed a set of recommended key next steps:

1. Leverage the information requirements that have been developed by various international transportation agencies to create/update (to the extent possible) AIRs in the U.S.
2. Liberate data from all the silos to streamline business processes.
3. Avoid vendor lock-in to maintain access to all information.
4. Prevent data lock-in within IT systems (whether developed in house or provided by a vendor).
5. Keep data in an open format in the long term.
6. Adopt open data standards for ease of information exchange and reliable archiving.
7. Prioritize BIM-related development in the following order: Consistent terms and definitions, classification systems, and object-based data modeling.
8. Evaluate IFC and GML-based standards as the predominant data modeling and exchange standards for asset information exchanges across the life cycle (to include project delivery and operations and maintenance). IFC 4.2 has objects defined for Roads and Bridges. Those objects can be used to establish OTLs and create UMLs. GML-based modeling standards such as InfraGML and CityGML also have such objects. They are all extensible and additional objects and properties can be incorporated.
9. Conduct a more in-depth analysis of the European practices in the use at the project level to organize asset information and provide it to the O&M phase by adopting open BIM standards.

4. BIM in Practice

CHAPTER SUMMARY

- BIM organizational structure, roles, and responsibilities should be defined both at the enterprise (agency) level and at a project level. Execution of BIM projects should be managed formally using BEPs.
- EIRs and models should be provided to contractors during procurement (in addition to drawings) to establish expectations on project delivery. As part of these digital information modeling and delivery requirements, model development specifications should be clearly outlined (e.g., model delivery schedule).
- Use of open standards and development of object-based data models should be encouraged during the project. Tools that facilitate interoperability and integration of the developed CAD, BIM, GIS, Point Cloud (LAS/LAZ) and internet of things (IoT) data models should be used.
- A CDE (as defined by ISO19650) should be set up as the information exchange platform.
- Design data models should support clash detection, visualization, quantity takeoff calculations, fabrication, automated machine guidance, and asset information requirements. NPRA specifically notes that, for asset information, GIS-systems are more relevant and, therefore, design data must be in a format that makes it easy to move them or export them to a format read by GIS systems.
- Contractors should submit an as-built data model in a specified format (owner agency not responsible for data transformations) for hand-off to asset management. The owner agencies are responsible for creating the specification for the contractors as part of the contract. The model-based contracts created for each project type should establish how the data models will be created and updated during the design and construction phase, especially when changes have to be made to as-design models, and, when contractors have to be paid for the as-built asset based on the information in the as-built data models.

4.1 Introduction

In chapter 4, it was established that the European countries that were interviewed as part of this study have a common understanding of the building blocks of BIM for infrastructure. These countries have embraced BIM by taking concrete steps toward deploying these building blocks by establishing information requirements; adopting open-standard based classification systems, ontology, and OTLs; and by enforcing data management processes.

Enforcement of data management processes has required that “model contract templates” are created, and clear “requirements associated with the functioning and use of data models” are established.

This chapter provides examples of projects and pilots that have been taken up by these countries. These pilots/projects demonstrate how these countries have been deploying and operationalizing the fundamental building blocks of BIM in practice. The project examples presented in this chapter show:

1. An organizational structure has to be established on BIM projects with clear definition of roles and responsibilities of BIM personnel involved in producing identified BIM deliverables.
2. Information requirements are defined in the contract (during procurement) and model is used as a contract document by owner agency and contractor.
3. Open and object-based data modeling and exchange standards are being utilized. Tools and technology are supporting integration and interoperability of data models.
4. Data are being managed in common data environments for efficient project delivery and asset management handoff.

From the perspective of the U.S., the examples corresponding to each of these features associated with BIM for infrastructure deployment are important for the following reasons:

- Several U.S. State DOTs have been looking for examples and experiences of other agencies in how these BIM features are implemented in practice.
- BIM implementation practices in the U.S. and Europe are being supported by similar data modeling, integration, and management tools and standards. Therefore, project experiences from Europe are transferable to the U.S.
- These examples reinforce and propel several ongoing and planned national initiatives related to BIM deployment in the U.S.

Project examples are presented from Sweden, UK, Finland, and the Netherlands. The critical success factors that should be considered in evaluating how well BIM is implemented in practice are listed in table 4-1. Corresponding to each of the factors, the key components that should be considered in assessing the maturity of an agency/country in operationalizing BIM in practice are also presented.

Table 4-1. Critical success factors and components assessed to measure BIM implementation maturity.

Critical Success Factor	Key Components
A. Organizational structure, i.e., BIM roles, responsibilities and management structure	BIM execution framework and template documentation (e.g., BEP, OIR/EIR/AIR and MPDT templates) Master Information Delivery Plans (MIDP) BIM administration roles and responsibilities
B. Data modeling, exchange and interoperability requirements, and standards and processes	Information requirements (OIR, EIR, AIR) Classification system, ontology and object-type library Project procurement using model as a contract document Data model features and use as outlined in table 3-4
C. CDE and data management tools	Data modeling and exchange tools Data management system for documents, drawings, models BIM execution and implementation quality tracking tools

The "organizational structure" success factor is critical for ensuring that the building blocks of BIM for infrastructure are effectively utilized in practice, i.e., on infrastructure projects. The key components of this success factor include: (a) BIM execution framework that comprises of template documents that outline the standard management procedures (SMPs) and serve as guidelines or playbooks for BIM implementation; and (b) BIM administrator roles and responsibilities, such as BIM manager, Model and Data Coordinators, etc.

The components associated with the factor "data modeling, exchange and interoperability requirements, and standards and processes" were discussed in detail in chapter 3 and were established as the building blocks of BIM for infrastructure. They include: (1) information requirements; (2) classification systems, ontology, and OTL; and (3) BIM data processes that involve using model as the contract document and creating them for addressing asset information requirements, clash detection, quantity take-off calculations, and automated machine guidance (see table 3-4 for the full list of features associated with models).

The "CDE and data management tools" dimension has been presented to show how the data modeled (to meet the information requirements established in the contract during procurement) is being managed to ensure that it can be shared and used across asset life cycle.

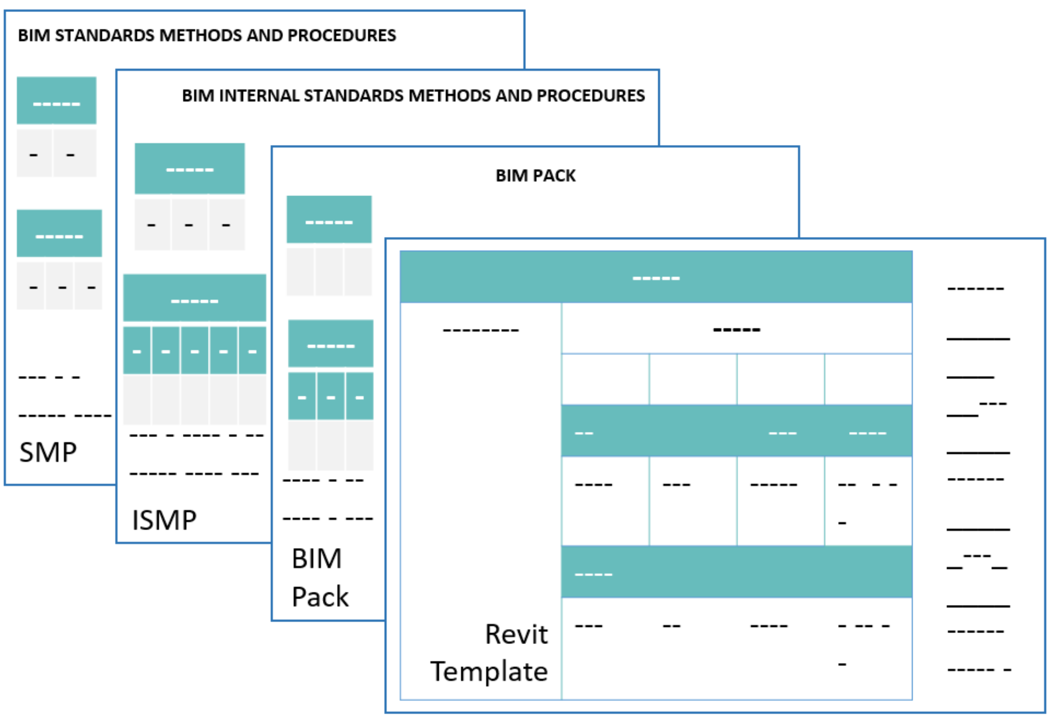
4.2 Organizational Structure: BIM Roles, Responsibilities and Management Structure

On any infrastructure project, an organizational structure is required for managing the processes, contractual requirements, data, and information workflows. In that regard a BIM project is not different.

4.2.1 Gatwick Airport, UK

Gatwick Airport is the second largest airport in the UK. All projects at the airport are managed by the owner agency, i.e., the Gatwick Airport Limited (GAL). BIM processes and principles have been created and adopted by GAL and its BIM implementation partners on more than 200 airport renovation and rehabilitation projects[32] since 2012. The application of BIM has significantly transformed project delivery and asset management at the airport.[33]

BIM Execution Framework and Template Documentation: A standard methods and procedures (SMP) document has been created by GAL for both internal and external procedures. A "BIM Pack" has also been created to ensure that projects use a consistent and systematic process.

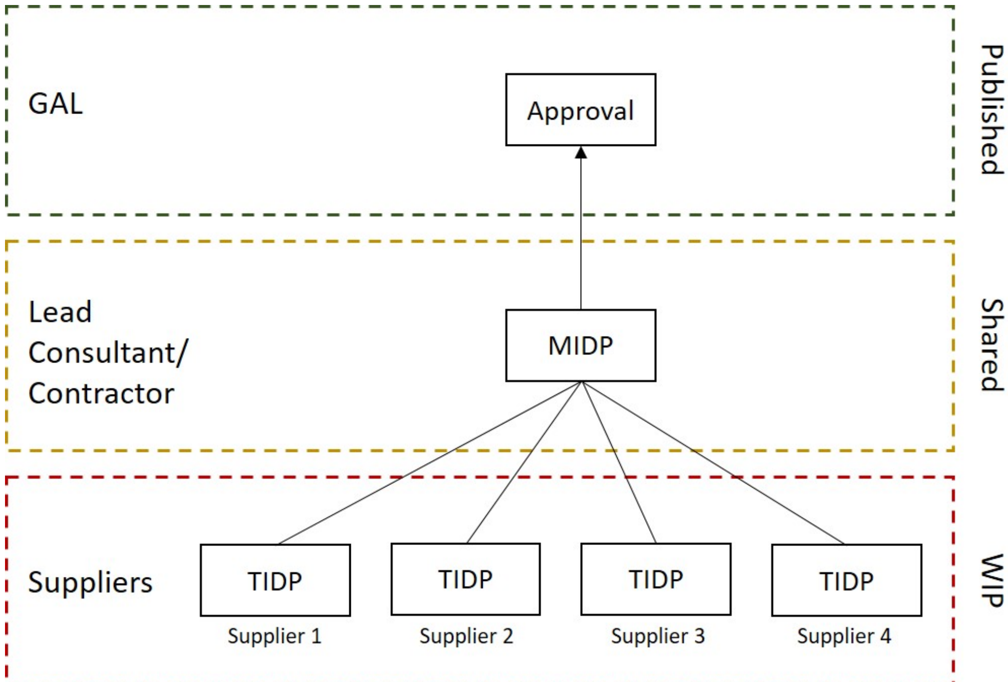


Source: Lewis Watts, Gatwick Airport (2019)

Figure 4-1. Illustration. Gatwick Airport—establishing BIM execution framework through SMPs and templates

[32] Gatwick Airport BIM Projects, Bechtel BIM (2014). https://www.youtube.com/watch?v=3sEU3BGtxho.
[33] Hulse, Rod & Codd, Andy & Neath, Stephanie. (2014). Building information modelling in practice: Transforming Gatwick Airport, UK. Proceedings of the ICE - Civil Engineering. 167. 81-87. 10.1680/cien.13.00018.

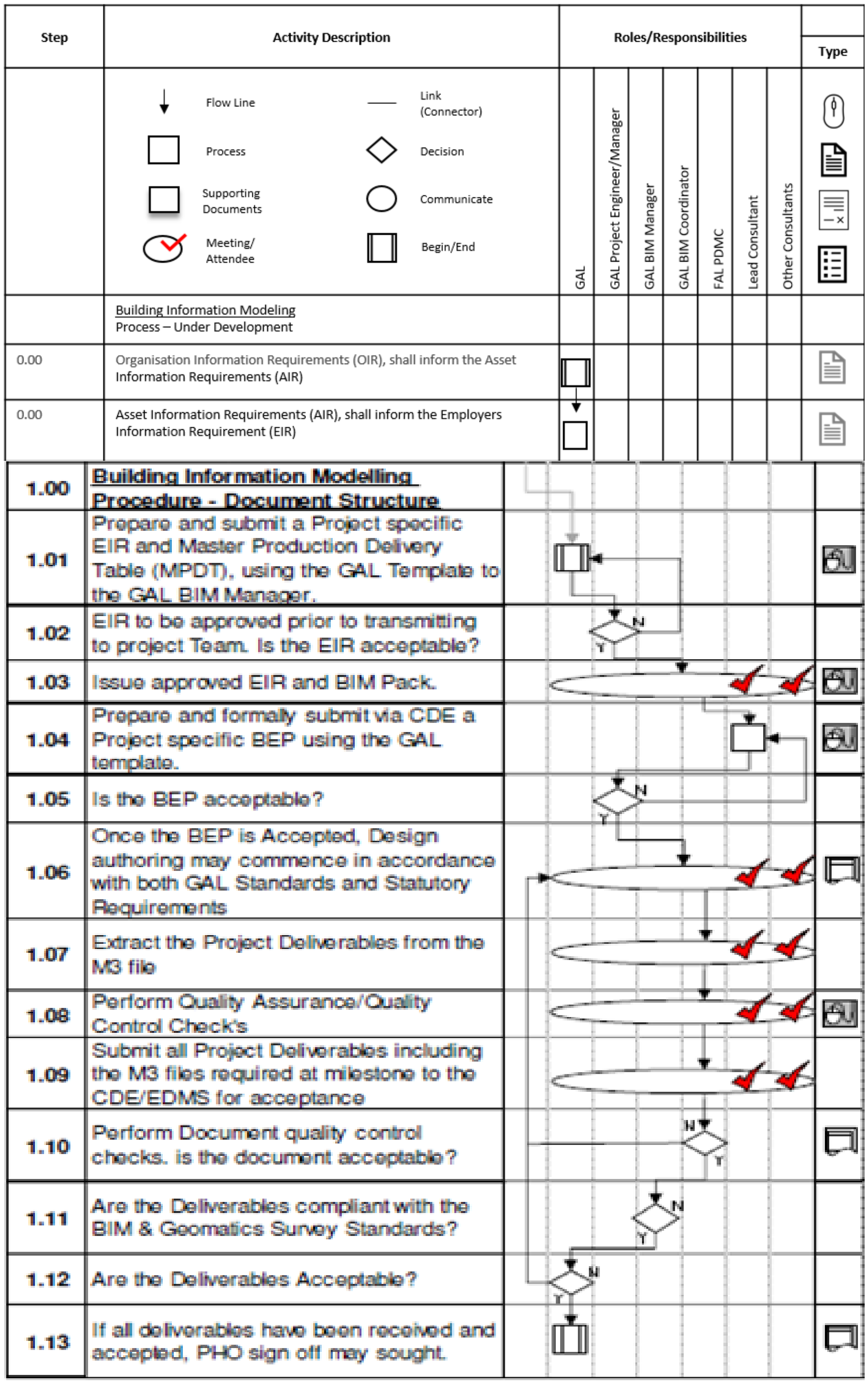
An example of the BIM management process step that is required and executed on all Gatwick Airport projects is creation of a master information delivery plan (MIDP). MIDP is created to ensure that a formal governance structure is in place for information to be shared between all the suppliers and the lead consultant/contractor, before it is submitted to GAL for approval at any stage of the project (figure 4-2).



Source: Lewis Watts, Gatwick Airport (2019)

Figure 4-2. Illustration. Gatwick Airport—Master Information Delivery Plan (MIDP)

BIM Administration Roles and Responsibilities: For executing BIM policies, processes, and standards during project delivery, the following roles are defined: (a) GAL project engineering manager, (b) BIM manager, (c) BIM coordinator, (d) project document management control (PDMC), and (e) lead consultant and consultants. The *GAL project engineering manager* is responsible for preparing EIR and MPDT, which are then sent to the *BIM manager* for review and approval. The *BIM manager* would then distribute the approved EIR and BIM package to the rest of the project team. The *lead consultant* is responsible for creating a BEP and submitting it to the *BIM manager* through the CDE. After the BIM manager approves the BEP, it is circulated to the rest of the team so that project deliverables can be prepared and taken through the PDMC, before being submitted to the *BIM coordinator* and *project engineering manager*. Figure 4-3 summarizes these BIM project activities, roles, responsibilities and information workflows.



Source: Lewis Watts, Gatwick Airport (2019)

Figure 4-3. Illustration. Gatwick Airport—BIM roles, responsibilities, and information workflow.

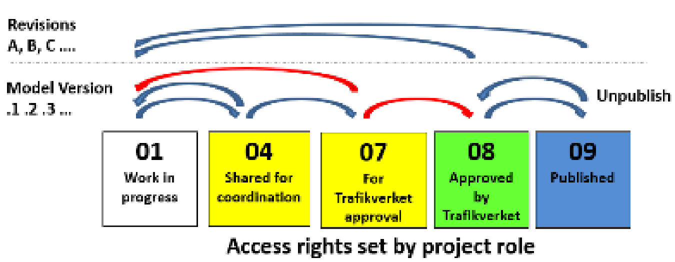
4.2.2 E4 Stockholm Bypass Project, Sweden

Stockholm is the capital city of Sweden, with approximately 2.5 million people living in the urban, metropolitan, and municipal area. The urban area is growing with approximately 100 people moving into the area every day. To support the needs of the growing region, the E4 Stockholm Bypass Project was undertaken by the Swedish Transport Administration, Trafikverket. Construction started in 2014 and is expected to complete in about 10 years, for an estimated €3.27 billion (2018 price). The project spans approximately 21 km, of which 18 km is covered by tunnels. It also involves building six interchanges and three lanes in each direction. By 2035, approximately, 140,000 vehicles are expected to use the motorway (highway) every day.

The project has 13 big civil construction contracts and three of these are tunnel excavation contracts. These contracts are divided into non-overlapping geographic parcels. Contractors from multiple countries in Europe (Sweden, Germany, Italy, Spain, and Turkey) are involved. Also, five design and build contracts have been purchased for all the installations in the tunnels and interchanges (e.g., telecom systems, electricals, lighting, tunnel ventilation, and intelligent transportation systems for traffic, drainage, and firefighting systems).

Given the magnitude of the project, it was decided that BIM would be used on the project from the beginning and object-oriented models will be used as the contract documents. Drawing will scarcely be used. The contractors will have the ability to choose desired modeling tools, but the models will have to be created, updated, and exchanged frequently between stakeholders. As a result, project team recognized the need to establish a robust organizational structure for management of BIM processes involving creation and exchange of data models.

BIM Administration Roles and Responsibilities: BIM model and data coordinators have been deployed across the five site offices. They are required to have experience in the use and management (navigation/exchange) of data models, in addition to traditional data/document management practices. A key responsibility of these modelers and coordinators is to ensure that the coordination models are kept up to date for the Trafikverket on-site staff. They are also responsible for training of the on-site staff in CAD software and associated processes required to view the models. Figure 4-4 presents the model development, coordination, approval, and publication workflow that has been established on the project. The design and build contractors create the models and share with the coordinators who review, ensure model interoperability and submit the models for approval by Trafikverket.



Source: Karin Anderson, Senior BIM Manager, Major Investment Projects, Trafikverket, Sweden (2019)

Figure 4-4. Illustration. E4 Stockholm—model development, coordination, approval, and publication workflow.

4.2.3 Espoo Salo Pasila-Riihimäki Railroad Projects, Finland

The Espoo Salo Railroad project was a preliminary design project on a railroad in Finland that involved constructing a 94 km railroad, 23 tunnels, and 120 bridges.

BIM Execution Framework and Template Documentation: For creation of the BIM data models and execution of BIM on the project, a master plan was created as part of the project. This plan documents the BIM organizational structure, processes, policies, and digital data management approach that will be used on the project. The plan also lays out how data will be shared and used by stakeholders through tools that are used for model visualization.

BIM Administration Roles and Responsibilities: BIM execution roles and responsibilities were defined on the project. For example, a digital coordinator role was defined. This role was responsible for creating the master plan, digital plan and perform data quality checks. The digital coordinator would also coordinate with the three design groups that were part of the BIM Team.

The Pasila-Riihimäki railroad project was a construction project on a railroad in Finland that involved renovation of the busy rail terminal area. The railroad would comprise seven tracks, and as part of the project, work would be done on all seven tracks. To avoid closing down the entire railroad, it was decided that four of the seven tracks would be kept open for operation all the time during the construction period. The BIM model based collaboration with all parties and stakeholders and simulation were used to succeed the construction when the traffic was on. BIM data models were created to allow for efficient tracking and management of safety and data quality issues.

4.2.4 RWS Projects, The Netherlands

BIM Execution Framework and Template Documentation: In the Netherlands, RWS uses systems engineering (SE) principles on BIM projects to ensure that formal processes are followed for management of requirements, risk, verification, and validation. The SE process involves establishing clear BIM roles, responsibilities, processes, and project organizational structure. As of September 2017, RWS had 27 active BIM projects, starting one by one from June 2012. Of these, 14 projects were in the execution phase; 3 projects were planned to be closed in 2017-2018; and 7 projects were in the planning phase (3 DBFM, 3 D&C) and were expected to remain in this phase during 2018-2020. RWS Procurement Services has created an information delivery specifications (IDS) template document that is to be used on projects before the discussions with vendors begin. The template should be filled by RWS data owners. To ensure that the data owners have a model-based collaborative data environment, a data room is created. By the time the contract discussions come to an end, RWS uses the IDS to describe the terms and conditions that should be agreed to by RWS, contractor, and other stakeholders. These terms and conditions establish the information and communication technology related processes that will be followed, including expectations regarding data management. The contractor is responsible to structure the data according to the RWS OTL and exchange the data with the use of the COINS standard (basically a zip file with a folder structure being able to contain an OTL). During the project, the contractor is responsible for preparing and populating the “containers of information (called COINS),” sharing them with stakeholders through the construction management database, and updating periodically before the final version is submitted to RWS’ project organization after construction is complete. The process of updating and formal approval of sending and retrieving, accepting the container with info is guided by the open standard VISI.

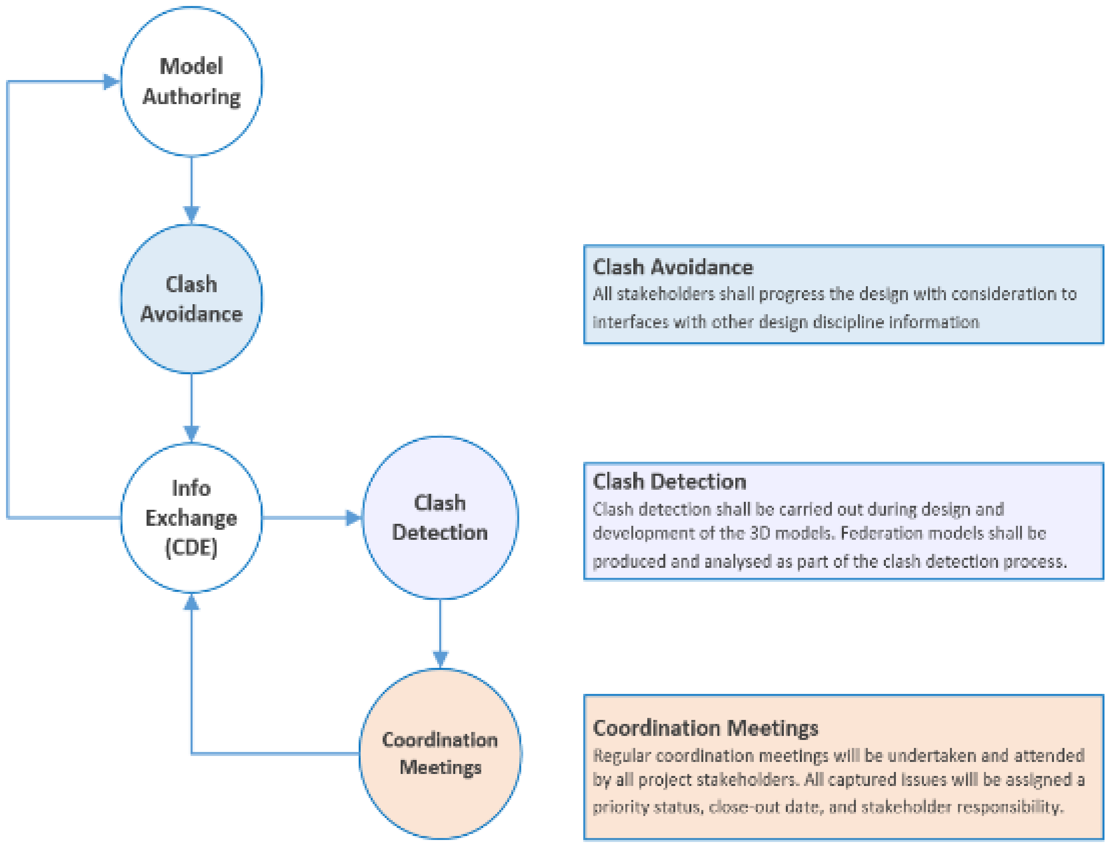
4.3 Data Modeling, Exchange, Interoperability Requirements, Standards, and Processes

The building blocks for BIM for infrastructure were established in chapter 3. Each of the building blocks presented is a key component in the assessment of the level of maturity of BIM implementation in practice. This section presents examples of projects where Organizational Information Requirements (OIR), Employer Information Requirements (EIRs), and Asset Information Requirements (AIR) were established by owner agency and included formally in the contract document to ensure that the data models created during the project have the required information and comply with the modeling standards and features associated with creation and use as outlined in table 3-4.

4.3.1 Gatwick Airport, UK

Information Modeling Requirements and Model as Contract Document: At the Gatwick Airport, the OIRs are developed by GAL and used to create the AIRs. In the AIR, all the asset types (object types) corresponding to which information should be recorded are identified and listed by the "function" the asset would perform. Each asset type is given an asset code, and the specific properties that need to be captured for the asset type are identified. For each asset, multiple property sets are defined in the AIR, including one that identifies the data requirements of asset managers, so that the information can be included in the model during design and construction phase and handed off to asset management at the end of the project. The AIRs are used to establish EIRs and the MPDT by GAL and made part of the contract. The contractor uses the MPDT to create and submit a BEP, which shows how models will be created during various design stages and construction to meet requirements.

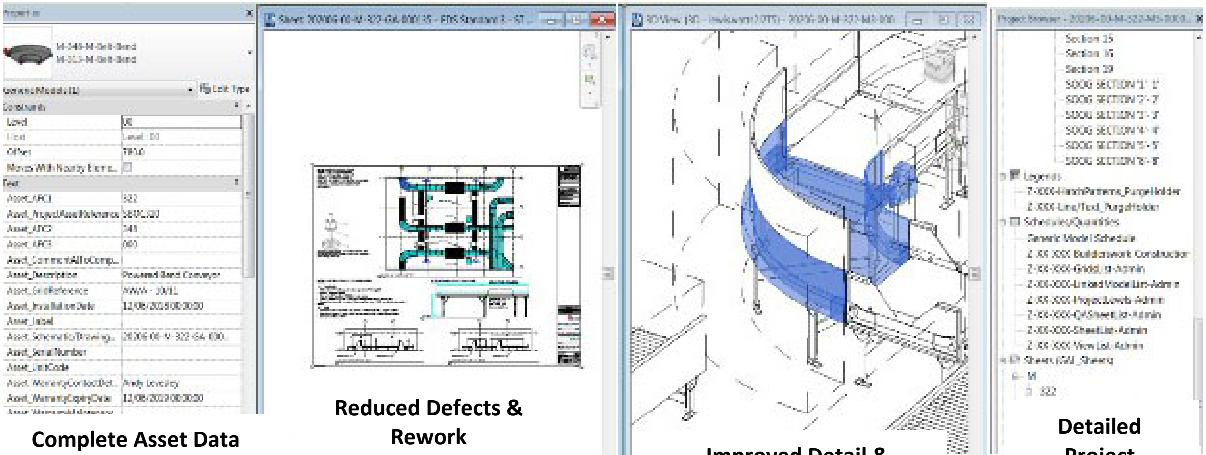
Model Creation, Visualization, Integration, Validation, and Use: GAL has established formal processes for model creation/authoring which also establish guidelines for all authors to avoid clashes with models being developed by other design disciplines. Models created by all the disciplines are integrated in the CDE to produce a federated information model, which is then used for clash detection. The issues identified during the clash detection process are tracked individually and resolved through discussions and coordination meetings. Figure 4-5 presents this model progression process. The issues are tracked through BIM reporting and tools, which are discussed later in the section on the CDE and data management tools.



Source: Lewis Watts, Gatwick Airport (2019)

Figure 4-5. Illustration. Gatwick Airport—model progression: create, integrate, detect clashes, and validate.

The model progression process adopted by GAL ensures that the number of defects and rework during construction is minimized and the project risk is reduced. The use of MPDT in the creation of the model ensures that the models are developed with the detail that is available about the built assets at various stages of the project. Additionally, the models are built with the asset details that are required as per the requirements established in the contract (i.e., in the AIR). By ensuring that the required asset data are included in the model, GAL can seamlessly hand over project data models to asset managers for development and maintenance of asset information models. Figure 4-6 summarizes these modeling practices and model features. Overall, GALs process for BIM model development, integration, validation and use meets most (if not all) of the BIM data modeling standards outlined in table 3-4.



Source: Lewis Watts, Gatwick Airport (2019)

Figure 4-6. Illustration. Gatwick Airport—BIM models used to address asset information requirements, hand over asset data to asset management, and improve efficiency of project delivery teams

4.3.2 E4 Stockholm Bypass Project, Sweden

Model Creation, Visualization, Integration, Validation, and Use: In the E4 Stockholm Bypass project, the models have been included in the contract as "contract documents" and are used to describe the data modeling and information collection requirements at the beginning of the project. Trafikverket established expectations regarding development of object-oriented 3D BIM models in the tender packages to ensure that contractors understand that credible models have to be developed and updated during the project. Expectations related to goals and vision of the organization and the importance of integrating the data models created by all the contractors was also clearly established at the procurement stage. For example, following expectations were established with respect to development and quality of data models.

- Object-oriented 3D models must be used in design, tender of documents, and during construction.
- Models should be perceived as more accessible and practical for communicating design solutions and technical solutions, than drawings. Very few drawings should be produced by designed and construction contractors. Focus should be on interoperable 3D models.
- Consultants and contractors are free to choose the data modeling tools as long as the models created are interoperable and can be integrated with other data models created on the project.
- Better design documents with fewer errors should be accomplished using coordination models for technical review, quality control, clash detection, quantity take off, and construction control.
- Better design and coordination models with all areas of technology must lead to:
  - Better quality of review and thus fewer errors.
  - Lower project cost estimates through more accurate bill-of-quantities.
  - Fewer change orders during construction due to errors in design.
- The CAD layer coding should be in alignment with the BSAB/CoClass standard.

- The models used during construction should be the same as the ones that were used when in the contract documents, after design was completed. Updates should be made to the design and the updated model should be reviewed/approved before use in construction activities.

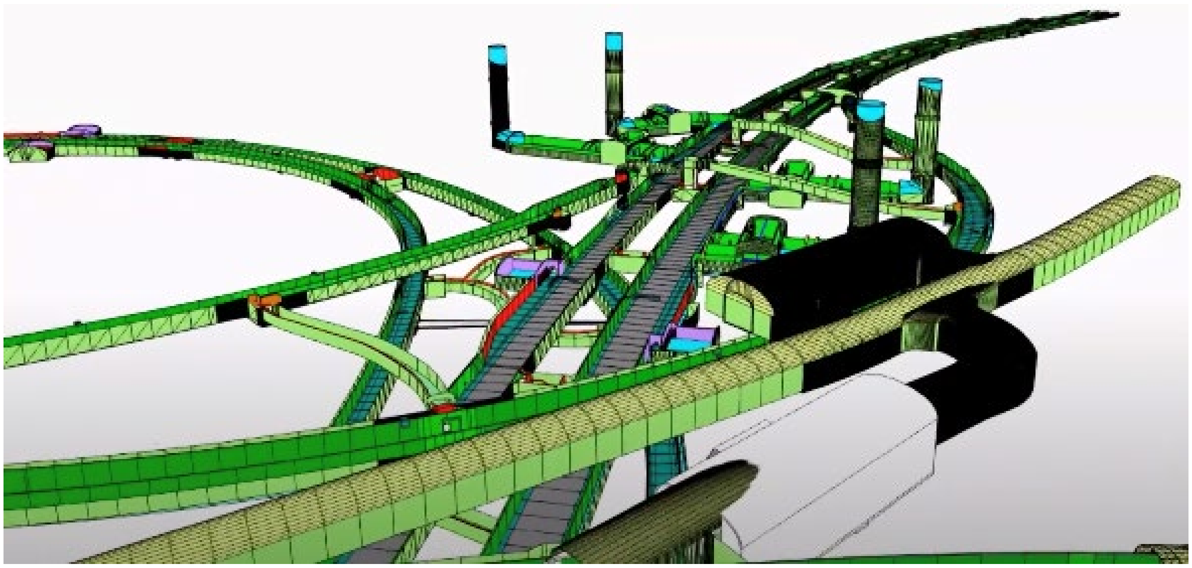


Figure 4-7. Illustration. E4 Stockholm Bypass project—integrated and quality controlled 3D BIM model.

4.3.3 Espoo-Salo and Pasila-Riihimäki Railroad Projects, Finland

Information Modeling Requirements and Model as Contract Document: Finland has created common infrastructure modeling requirements. These requirements were created for managing model-based projects and ensuring that general modeling requirements are available across all projects. The specifications included: (a) creating requirements for initial information documentation (b) creating requirements for modeling in different design phases, (c) establishing structural modeling requirements, for structures such as Earth, foundation, and rock constructions; pavement and surface structures; bridge and other engineering structures. Such specifications have been used for establishing information modeling requirements on multiple projects, including the Espoo Salo Railroad and Pasila-Riihimäki project.

In addition to the railroad projects, another example of a project in Finland where BIM has been implemented is the Highway 4 Äänekoski road project. On this project, the BIM model was used as the contract document by both FTIA and the contractor. The model was checked every week by the contractor and the payments were made against the model. The models were created and stored using open file-based data modeling and exchange standards such as LandXML and InfraModel.

Model Creation, Visualization, Integration, Validation and Use: For creating data models and exchanging data during design and construction, Finland is using LandXML based Inframodel 3 or 4 version to model project details, terrain, roads, water supply, sewerage, railways, equipment, and soil inventory. Currently, Inframodel 3 is not used for creating data models in asset management applications. Inframodel-based BIM models are being used in both railroad construction and highway projects.

Additional properties (attributes) and property sets have been added to InfraModel. In addition to LandXML based InfraModel, FTIA has also been using the IFC as an information requirement in bridge projects that exist in the IFC standard since 2015. As discussed in chapter 3, with the release of IFC 4.2 and availability of IFC bridge and road object types that are specifically used to model highway infrastructure elements, FTIA is now looking into adopting and migrating even more to IFC.

As part of the Velho implementation, FTIA has chosen Vektor3 (www.vector.io) as the integrated BIM tool of Velho system that will be used for viewing the 3D BIM model. Vektor3 is a web-based BIM tool that has been created by a Finland-based software company called Vector.io. Vektor3 allows for rapid processing and integration of multiple complex and large data models, irrespective of whether they are 2D/3D-BIM or CAD models, GIS files, and IoT data models. The tool can be used on mobile or desktop platforms and can be used to see full detail in the data models. All digital information can be loaded on one platform. The data can be brought in any format, for example: IFC, DWG, LandXML, InfraModel and/or LAS/LAZ. All these types of data are automatically combined, thus creating a unified data experience on a single platform. It supports all relevant coordinate systems and data formats, whether it is maps, point clouds, and infrastructure models, to building information models and IoT data. To ensure that the data models created during design and construction phase comply with InfraModel data format specifications, FTIA has deployed a software tools called Infrakit (www.infrakit.com) and BimOne (www.bimone.fi).

4.3.4 RWS Projects, The Netherlands

Information Modeling Requirements and Model as Contract Document: RWS has established asset information requirements for BIM (referred to as the AIRBIM program), to ensure that asset data are being captured consistently across all projects. The information requirements are part of the IDS and are used to establish modeling requirements and model as the contract document.

Model Creation, Visualization, Integration, Validation, and Use: In the Netherlands, for data modeling during design and construction phase, interoperable open and proprietary standards such as LandXML, DGN, DXF, and CityGML-based IMGeo are being used on infrastructure projects. For data exchange, RWS has created the COINS (Construction Objects and the Integration of Processes and Systems) national standard. Furthermore, RWS has initiated a library of terms (buildings and infra related), referred to as concept library (CB-NL) for use across projects in the nation to ensure that the same terminology is being used across all of them.

4.4 CDE and Data Management Tools for Efficient Project Delivery and Handoff

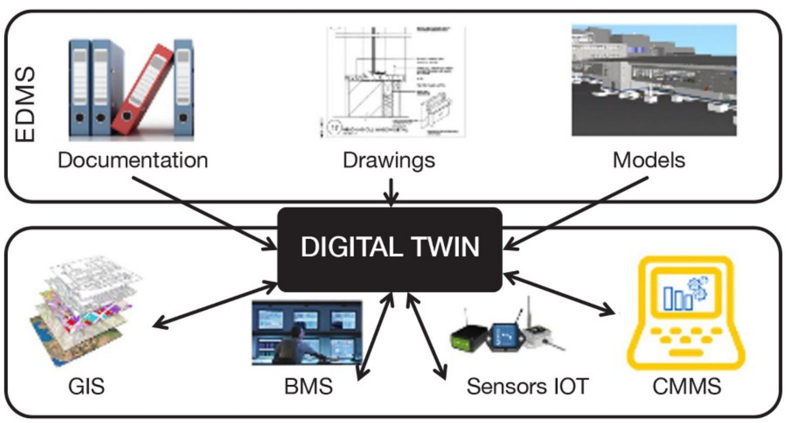
4.4.1 Gatwick Airport, UK

On the Gatwick Airport projects, GAL uses the following BIM data management and communication tools for creating, storing, and integrating data models:

- **BIM Data Modeling and Exchange Tools**: BIMONE, BIM360, and BIM Track have been used to ensure model interoperability between proprietary systems and establish a communication platform between stakeholders involved in model creation, integration, clash detection, and issue resolution.

- **Data Management System and CDE**: ProjectWise is used as the electronic document management system (EDMS). It serves as the collaborative work environment and supports workflow-based data integrations.

  GIS, Building Management System (BMS) and Maintenance Management System (MMS) are used for storing and managing the asset information model that is created at the end of the projects.



Source: Lewis Watts, Gatwick Airport (2019)

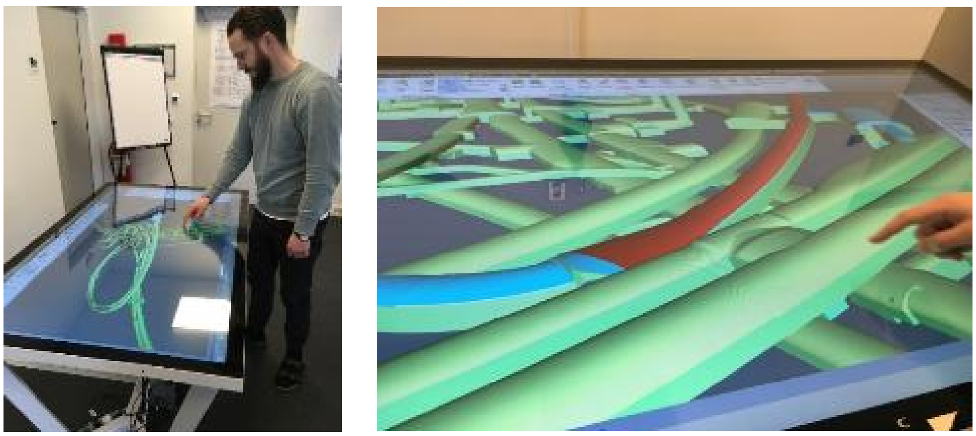
Figure 4-8. Illustration. Gatwick Airport projects—asset information management systems populated with asset data in the projects EDMS.

- **BIM Execution and Implementation Quality Tracking Tools:** Microsoft Power BI is used for reporting and tracking of the quality of the BIM project. Source: Lewis Watts, Gatwick Airport (2019)

4.4.2 E4 Stockholm Bypass Project, Sweden

The BIM data management tools being used in Sweden include ProjectWise document management system (for storing and sharing of documents), ShareFile file sharing system (for enhancing communications), and Autodesk Navisworks.

- **BIM Data Modeling and Exchange Tools**: Navisworks is used by engineering and construction workers to create, visualize, and review the 3D digital models. The software models are displayed on a high-resolution 65" horizontal touchscreen (Figure 4-9) for model review and engineering discussions.[34]



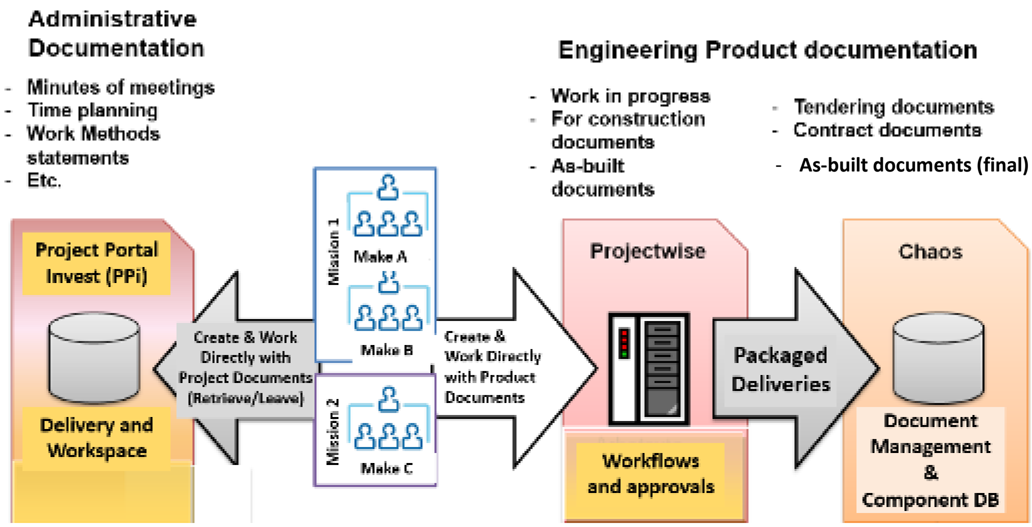
Source: Karin Anderson, Senior BIM Manager, Major Investment Projects, Trafikverket, Sweden (2019)

Figure 4-9. Illustration. E4 Stockholm Bypass Project—BIM model coordination on a 65-inch screen.

- **Common Data Environment and Data Management Tools**: Technical specifications have been established to ensure that ProjectWise is used as the CDE during design and construction phase by all stakeholders. Two types of documents are stored in the CDE:
    - Project documents, which are documents that are needed for project management and administration. For e.g., memoirs, contacts, calendars, diaries, and activities.
    - Product documents, which are documents associated with the assets being engineered and constructed. These documents include drawings, CAD files, technical descriptions, investigations, reports, maintenance documentation, etc.

For each suppliers, the Swedish Transport Administration provides one (1) adapted and free training of the EDMS that is used during the project. All participants pay for their own time for training. The supplier is then responsible for training its organization. During the project, the EDMS is used for management of tender documentation, contract, models, and drawings created during construction, and the final as-built documents. All data creation, review, and approval workflows are tracked in the system.

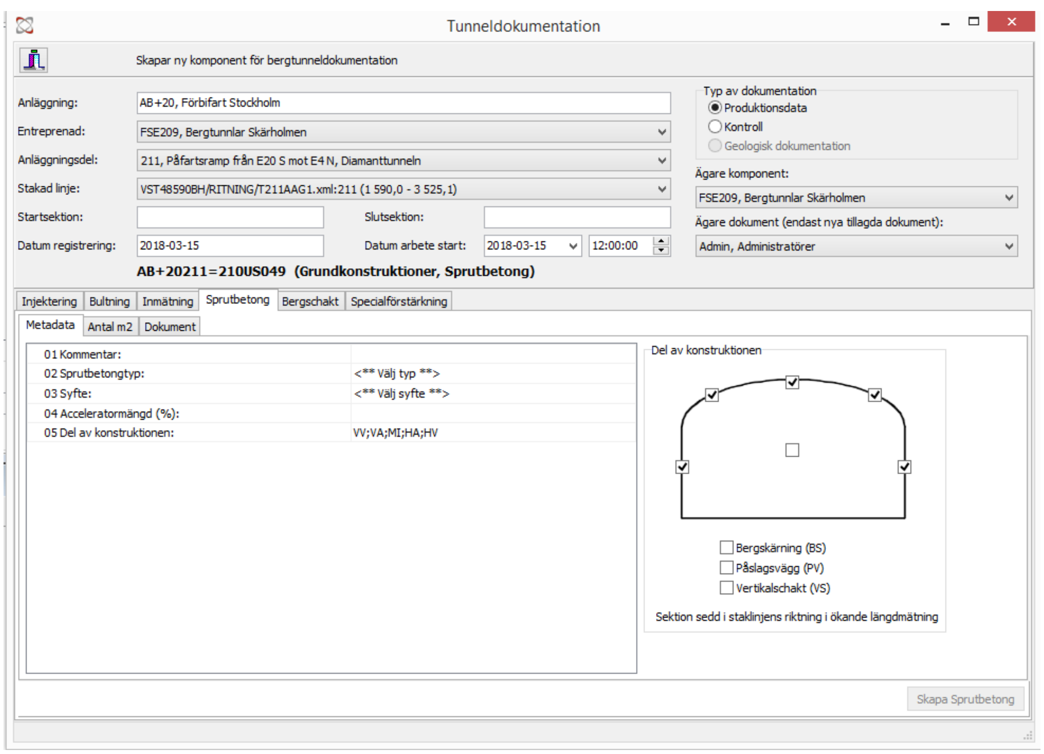
[34] Trafikverket. BIM work approach for the future. https://www.trafikverket.se/en/startpage/projects/Road-construction-projects/the-stockholm-bypass/bim--the-work-approach-of-the-future/



Source: Karin Anderson, Senior BIM Manager, Major Investment Projects, Trafikverket, Sweden (2019)

Figure 4-10. Illustration. E4 Stockholm Bypass Project—project document management system.

The project has developed a database called “tunneldok” for storing tunnel data that is created during production (Figure 4-11). This data in this system is used to follow up on progress and asset information modeling requirements.



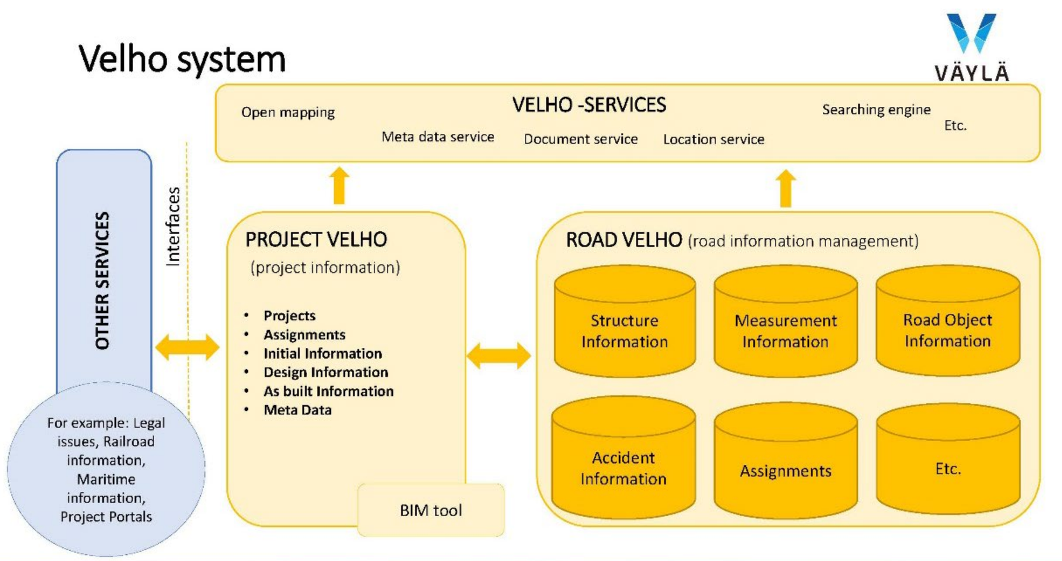
Source: Karin Anderson, Senior BIM Manager, Major Investment Projects, Trafikverket, Sweden (2019)

Figure 4-11. Illustration. E4 Stockholm Bypass Project—tunnel documentation data system.

4.4.3 Espoo Salo Pasila-Riihimäki Railroad Projects, Finland

Common Data Environment and Data Management Tools: Finland has been in the process of deploying the Velho Information Management System for managing project and road assets information. The system will serve as a central repository for managing plan, design, construction, and as-built data for road, rail, and waterway systems. Figure 4-12 presents an overview of the Velho system. The repository can be used by both internal employees, consultants, and contractors involved in project delivery to import, export, and view data. It is used as a storage to put data in at the end of the project, view it, and take materials out for the project. The tool is available throughout the design and construction phase to project delivery personnel to capture project information and store project materials such as documents, design plans. It serves as a common company project and design information portal during the design and construction phase, ensuring that all project data are being entered using a single collaborative data editing and management tool. Data entered through the project and design information portal of this BIM tool is stored in a systematic manner across various project and road information management databases.

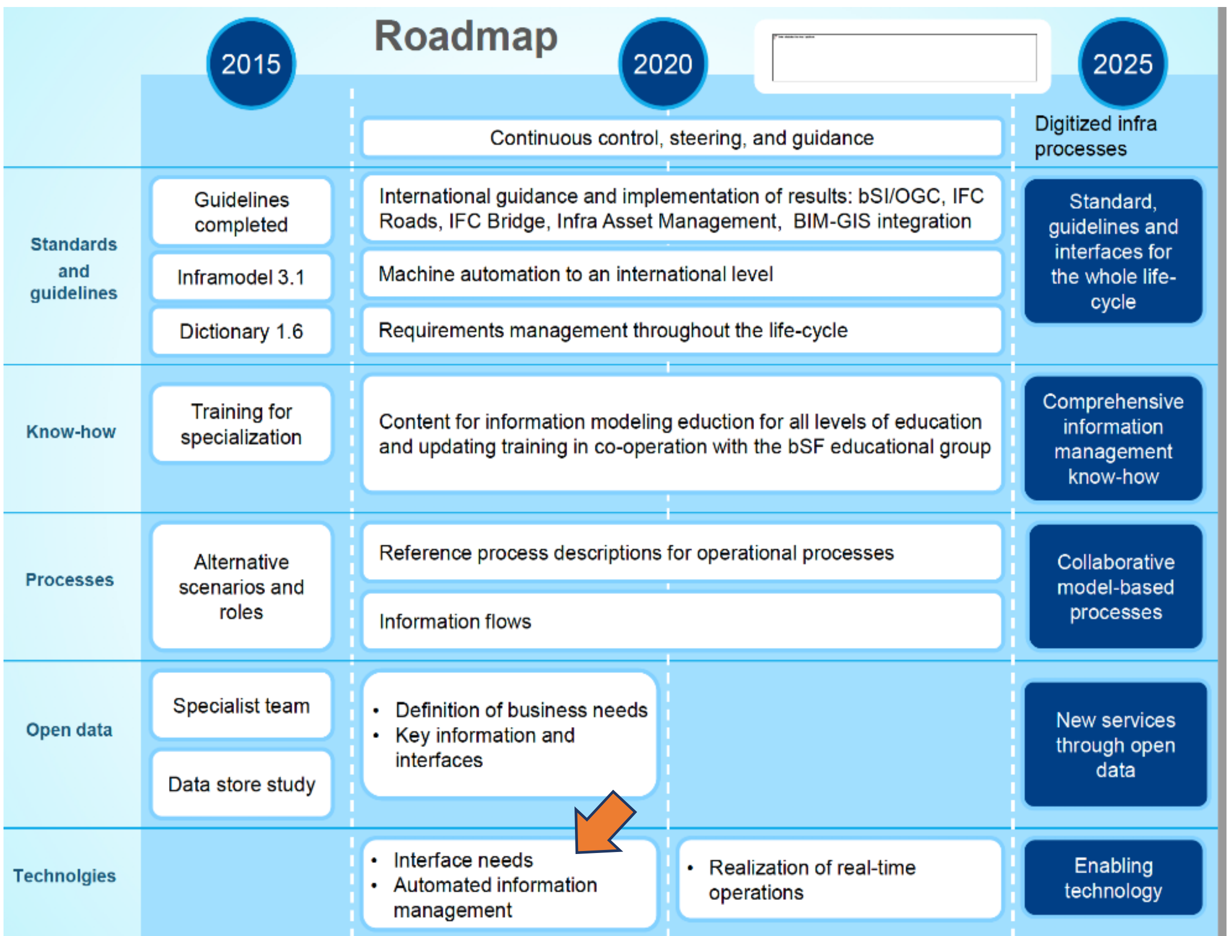
At the end of construction, as-built information will be in future after integration, automatically sent to the road, rail, and waterways information management databases, which are then used by asset managers in FTIA to operate and maintain the constructed facility. Therefore, the Velho information management system ensures that information is not only stored in a common data environment during the design and construction phase, but also sent to respective structure, road object, performance measurement, accident, and other such road information management systems. Velho integrated BIM tool is allowing to view the BIM models and their full information stored by any Velho user through internet. FTIA has also built web services as part of the Velho system that allows them to check the InfraModel file for compliance with the standard before it is uploaded. In addition to this service, there are other services offered by Velho system. These include open mapping service, document upload/validation service, metadata service, and location service.



Source: Tarmo Savolainen, Chief Specialist. InfraBIM Finnish Transport Infrastructure Agency FTIA (2019)

Figure 4-12. Illustration. Finland's Velho system for project and asset information management.

Velho implementation process is still going on in FTIA. Implementation of the Velho system has involved deployment of many other foundational pieces, including formulation of BIM policies and processes. As shown in the roadmap in Figure 4-13, implementation of "automated information management" systems deployment was built on the foundation of open standards, guidelines, processes, and use of open data models. The journey began for FTIA in 2014 and the agency has been committed to open BIM since then. BIM guidelines were developed for bridges (in 2015), followed by the policies for road and railways (in 2017). FTIA has committed to training on an annual basis. Since 2018, FTIA has had special consultant service called TiMaHa for its project managers to help them to define and set goals and tendering documents for BIM project, help implementation of the BIM process and check the final materials before acceptance. The journey will continue for the next 5 to 10 years, and FTIA's goal is to continuously evolve their technology tools so that they can deploy digitized infrastructure processes.

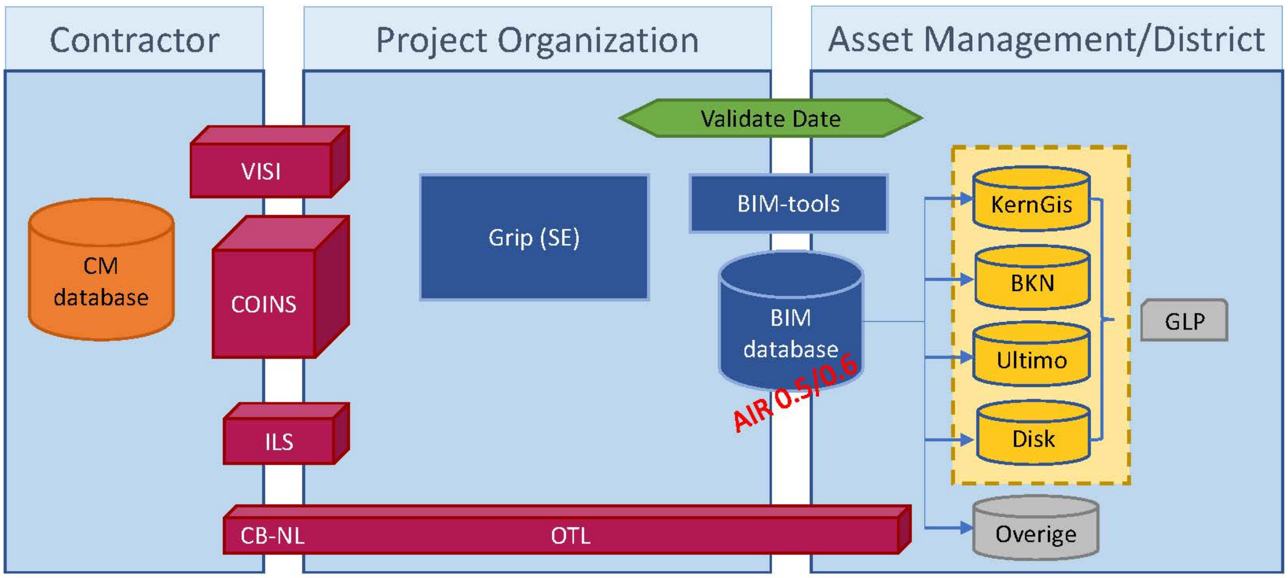


Source: https://docplayer.net/37366642-Bim-in-finland.html

Figure 4-13. Illustration. Roadmap of Finland's BIM processes, standards, data tools, and technologies.

4.4.4 RWS Projects, The Netherlands

Common Data Environment and Data Management Tools: In the Netherlands, RWS has been using a CDE as part of its BIM framework. During the construction phase, the contractor enters information in the construction management database; this information is made available using BIM tools to asset management in accordance with the asset information requirements (AIR) (see Figure 4-14). On at least 12 or 13 RWS projects, data were sent from project delivery to asset management using object-based data models, according to this process. RWS also setup a web portal, ProjectWEB, to share information about the project with stakeholders.



Source: Guus Pijpers, RWS (2017). BIM Projects at RWS

Figure 4-14. Illustration. RWS's approach to data management.

4.5 Summary of Capability Assessment

The critical success factors that should be assessed for measuring the maturity of an agency/country in implementing BIM in practice are presented in table 4-1. Table 4-2 summarizes the key takeaways from the project examples presented in this chapter corresponding to the host organizations in UK, Sweden, Finland, and the Netherlands.

Table 4-2. BIM implementation projects examples from UK, Sweden, Finland, and the Netherlands.

Projects	[A] Organizational Structure: BIM Roles, Responsibilities & Management Structure	[B] Data Modeling, Exchange, Interoperability Requirements & Standards	[C] Common Data Environment (CDE) & Data Management Tools
Gatwick Airport Projects, UK	Project engineer, BIM manager, coordinator administer BIM workflows	AIRs used to create EIRs, which are then used to create MPDT and project BEP	ProjectWise EDMS
E4 Stockholm Bypass Project, Sweden	BIM managers, data and model coordinators administer models across 5 site offices and 13 contractors	Models used as contract documents to establish object-oriented 3D model information requirements	Structured databases and document management systems (e.g. Projectwise) used to store data. Object-oriented database used to store assets data.
Espoo-Salo Railroad, Pasila-Riihimäki Railroad & Valatatie 4 Road, Finland	BIM coordinators work with design teams as per defined BIM project management structure and modeling rules.	Modeling requirements met by interoperable standards, such as: IFC, DWG, DGN, LAS, LandXML, Inframodel.	Different project portals and BIM tools selected by the project. In future all the information will be delivered to Velho system
RWS Projects, the Netherlands	Systems Engineering (SE), IDS, VISI used to established BIM management framework. IDS is established in a data room.	RWS OTL, COINS, IMGeo, CityGML, standards used for data modeling and exchange.	Construction management database, asset databases

In addition to table 4-2, Figure 4-15 was created to provide a quick comparison of how the practices in Sweden, Finland, UK, and the Netherlands can be rated on the three-point maturity scale (as per the methodology outlined in NCHRP Report 750, Volume 7). The general characterization of the levels is as follows:

- **Level 1**: The agency/country is in a relatively weak position in implementing BIM for infrastructure. There are significant gaps that need to be addressed to successfully deploy BIM in practice, i.e., on projects.
- **Level 2**: The agency/country is in a potentially tenable position to advance BIM for infrastructure but should address some gaps in implementing BIM on projects. Policies, processes, and standards associated with the building blocks of BIM have been formulated (as presented in chapter 3) but have yet to be effectively deployed in practice, i.e., on projects.
- **Level 3**: The agency/country is well positioned to implement BIM for infrastructure in practice. BIM has been used relatively successfully in the past on implementation projects and/or pilots,

lessons have been learned and documented, and a future roadmap for improved BIM implementation has been created.

Source: Original. Created by Authors.

Figure 4-15. Illustration. Perceived maturity of the various host organizations in relation to organizational readiness and capability to succeed in BIM implementation.

In constructing Figure 4-15, for every component of each success factor analyzed, agencies were given a numerical score of 1 (lowest possible score) to 3 (highest possible score) depending on the information they shared. All the component scores for a critical success factor were then averaged to represent the score for a given factor.

Only four of the host organizations were assessed, given the information available on BIM project implementations to the study team. In addition, the study team carried out the capability assessment in Figure 4-15 based on the evidence gathered during the discussions held during the visits and a post-study literature review of published information and documents obtained from the host organizations. The assessment was carried out to visually summarize the impressions of the study team and is not to be used for any other purpose. The host organizations were not involved with assessment.

5. Key Lessons Learned

5.1 Recommendations for BIM Implementation in the U.S.

Based on the key observations and lessons learned about the BIM practices in the host agencies, the study team developed the following set of key suggested recommendations.

Actions for "BIM Awareness, Leadership, Preparation, and Collaboration":

- Establish understanding of what BIM is and what it represents. In doing so, emphasize the importance of focusing on the fundamental principles and the type of actions needed instead of focusing on the term 'BIM.' This could involve establishing an understanding that BIM and GIS are not "separate worlds." Instead, the GIS data modeling standards are part of the larger BIM framework (more specifically, the spatial data properties and rules associated with BIM).
- Consider establishing State DOT-led BIM pooled fund program for Infrastructure so that a national leadership group of public sector experts can meet regularly amongst themselves and other stakeholders to shape and guide BIM related deployment activities.
- BIM State DOT pooled fund leadership could establish a program of activities that lay out a clear vision and tactical steps to mainstream the implementation of BIM activities. This should be done in consultation with all market parties who will either be impacted by the change or will enable change. These parties include but are not restricted to contractors, consultants, fabricators, BIM service providers, and software vendors.
- Federal and State transportation agencies (including State DOTs, local, and Federal agencies) could identify representatives to participate in national pooled-fund studies and National BIM programs.
- A strong marketing and communications plan that articulates the benefits to owners and private sector of BIM (as 'information management' workflow) could be launched as a co-equal effort to technical activities.

Actions for Implementing the Building Blocks of BIM for Infrastructure: Organizational Structure, Data Modeling, Data Exchange, and Management Platforms:

- Identify, prioritize and execute BIM data and information management activities such as:
    - Adopt consistent terms and definitions to describe assets and asset networks.
    - Adopt classification systems to group asset objects and check whether they are fit for purpose (meaning covering the information need).
    - Adopt object-based data modeling techniques.
    - Adopt open data standards-based for ease of information exchange.

- "Liberate data" from all the silos to streamline business process, and keep data in an open format in the long run to ensure interoperability and usability.

- Standardize processes for data modeling and exchange, information delivery even if it means that deliveries happen through "closed" or proprietary processes as a step to achieving the open BIM vision. Liberate data from all the silos to streamline business processes.
- Compile and standardize information requirements. The requirements that have been developed by various international transportation agencies can be leveraged.
- Develop model-based contract templates, with information requirements for contractors to prepare and submit as-built assets data at the end of the project. The model-based contract templates should take into consideration the type of project (e.g., bridge rehabilitation/reconstruction, interchange modification, new road facility construction, etc.). The type of project dictates the modeling needs and information requirements. For example, on certain types of projects, bridge and tunnel models are needed, but on others such models may not be needed. The model contract templates should reflect such data modeling requirements for standard type of projects.

5.2 Potential Tactics for BIM Implementation

The following strategies and tactics could be followed to implement the recommended actions:

5.2.1 Tactics for Promoting "BIM Awareness, Leadership, Preparation and Collaboration"

- Facilitate activities to promote and/or demonstrate study findings to relevant partners, stakeholders, organizations.
    - National webinars/workshops and peer exchanges on BIM should be organized to share information about BIM activity progress with stakeholders.
    - Importance of data governance in establishing BIM standards and deploying BIM should be established with Data Offices and Governance Councils to align with larger data related or digitalization priorities of Governmental organizations.
    - Public sector should take an active role in industry-led BIM forums to ensure that their intentions and aspirations are widely known.

- Raise awareness of identified BIM innovations and best practices
    - BIM case studies on use of open international data modeling standards such as IFC, InfraGML, CityGML, linked data/semantic web should be presented by early adopters. Awareness of other geospatial data standards from OGC and TC 211 and how they compare with buildingSMART modeling standards such as IFC, should be established as part of this step, primarily to enable discussions related to how and what data should be captured and exchanged between data models that use these different standards.
    - Information about BIM data governance, data exchange and delivery platforms, tools and techniques should be shared. Model specification techniques such as UML, Express, and differences in the metadata information that is captured using each approach should be established to facilitate data exchange.

    - Standards-based information exchange packages that have been created and are being used at agencies must be publicized through demonstrations.
    - Model-based contracting templates, with asset and employer information requirements could be published.

- Client organizations should take actions to:
    - Avoid vendor lock-in to maintain access to all information. Also, prevent data lock-in within information technology (IT) systems (whether developed in house or provided by a vendor).
    - Initiate and pursue in-country and international collaborations as appropriate.
    - Anchor the findings to an organization that will undertake a wider technology transfer effort. Federal Highway Administration in partnership with its industry association partners can launch a technology transfer effort to mainstream the implementation of BIM through a series of training activities focused on: Workforce upskilling; Change management for project delivery and infrastructure management and maintenance; Technical topics; Plus aligning standards under development.

5.2.2 Tactics for implementing the "Building Blocks of BIM for Infrastructure"

- To manage the organizational cultural shift and change management:
    - Take small steps to go from "little BIM" (design-construction phase) to "big BIM" (all phases in asset life cycle).
    - Identify a workable maturity process (e.g., a roadmap) and adopt it.
    - Marketing and benefits documentation can be created for organizational buy-in.

- To develop and deploy data modeling and exchange standards, information requirements and model-based contracting templates:
    - Start with an in-depth case study of these artifacts at national and international transportation agencies and countries that have developed and deployed them in practice. Use the case-study analysis to determine what can be leveraged by agencies in the U.S.
    - Leverage the list of business use cases and data modeling requirements that have been created by agencies in the U.S. and in other countries.
    - Conduct workshops and peer exchanges to determine commonalities and variances in data modeling and management practices at transportation agencies.
    - Establish the expectation that the end goal of the exercise is not to standardize all data schemas and object-type libraries. Instead the goal is to preserve the autonomy of agency specific data needs, models and systems where required, and, standardize to the extent it is practical and feasible to do so. Data should be FAIR (Findable, Accessible, Interoperable, and Reusable).

Appendix A: Amplifying Questions

The following topic areas summarize the information that the U.S. study team explored during the BIM GBP study.

Focus Area: Leadership

Discussion around BIM leadership, specifically compelling drivers, visions, goals, and how the host agencies established the value of pursuing BIM.

- **Compelling drivers, visions, and goals**
    - What is your definition of BIM?
    - Has a countrywide BIM Roadmap been developed and published that includes highway infrastructure?
    - Which organizations or agencies are driving the BIM growth and development in the country—both on the public and private side?
    - What obstacles or challenges did you identify to successful implementation at the onset of your BIM initiative?
    - What are you doing incrementally to achieve goals?
    - What will success or implementation look like? What is the owner's vision?

- **Aligned value proposition and strategy**
    - Why are you implementing BIM for infrastructure?
    - What is the anticipated value of BIM?
    - What mechanism(s) were used to get buy-in within your agency?

Focus Area: Framework

Discussion around frameworks was centered on how each host country/organization supports the BIM goals, objectives, best practices, guidelines laid out by leadership, and to execute BIM activities such as: processes, data capture, collection, storage, sharing, exchange, archival, secure access, analysis, reporting, etc.

- **Policy (legal and contractual, procurement, specified data requirements, delivery plan)**
    - Are BIM deliverables required or incentivized for publicly funded construction projects?
    - How are contracts awarded? What delivery methods are used (Design-Build, Design-Bid-Build, Cost+, Design-Build-Operate-Maintain, others)?

- How does this picture change when private financing of one or more phases of the project's life cycle are involved, e.g., as in a design-build-finance-operate, maintain (DBFOM) or design-build-finance--maintain (DBFM)?
- Are requirements presented in a form that is approachable and understandable to users?
- Have model or sample contract documents been developed for different types of projects (Design-Bid-Build, Design Build, PPP), so that agencies can formally communicate BIM information requirements to contractors?
- What demonstrable successes have you had implementing standards?
- Are required attributes based on authoritative sources proven with broad engagement?

- **Technical (security, technical information, validation, use)**
  - What specific data are transacted during project delivery and operations and maintenance phases?
  - How is it validated and used?
  - How is data security being addressed?

- **Process (data exchange, collaborative working and coordination, information management)**
  - What standards are used for data and information exchange?
  - What software and hardware tools and technology have been deployed to enable data modeling and exchange per BIM standards?
  - How did legacy systems factor into your adoption/implementation of BIM?
  - Do you have any certification process, validation process, or acceptance process of the information being delivered by designers, fabricators, or the contractors?
  - Do you have data governance guidelines for data collection during construction?
  - Are contractors providing content that is required by agencies?
  - What is the overall process for developing, using, and maintaining models?

- **People (responsibilities, skills, capacity, incentives)**
  - Did you change or add any organizational resources for this effort?
  - Did you face challenges with organizational capabilities with BIM?

Focus Area: Communication

In addition to leadership and BIM framework deployment, another area or BIM pillar that was outlined for discussion was communications around BIM at the national and international levels.

- **Engagement with industry stakeholders**
  - What mechanism(s) were used to get buy-in from external stakeholders to advance BIM?
  - What efforts have been made to communicate with BIM software vendors?
  - How are you building capacity for industry to meet requirements?
  - What communication has been established with contractors submitting information?

Focus Area: Implementation

Finally, BIM implementation experience within each Nation was discussed. Specifically, projects where BIM was implemented and success/failures witnessed, lessons learned, and where in-house and contracting staff followed the BIM processes to create/collect, store, and exchange data as per BIM requirements, contractual documents were discussed.

- **Early wins, pilot projects, and training**
  - Are there formal training programs that have been developed to prepare BIM professionals?
  - What type of projects require adherence to BIM practices? What are the criteria for identifying such projects?
  - Which projects in the country are ideal examples (role models) from the perspective of BIM implementation?
  - Are there currently any pilot projects in the country that are being used to develop BIM implementation requirements and determine how BIM can be implemented nationally?
  - How is execution of the BIM processes being handled? Are their formal execution plans in place that define aspects related to how data will be modeled and exchanged?
  - How have contractors responded to pilot projects?
  - Have contractors been informed about the model evaluation process that will be associated with implementation of BIM projects?

- **Lessons learned**
  - From your perspective, what are the emerging technologies, processes, or workflows that would accelerate BIM implementation?
  - What obstacles or challenges were discovered during implementation?
  - If you had the opportunity to start over, what would you change? What would you keep? Why?
  - What do you wish you had known when you began this initiative in your organization?
  - What surprises did you find with your internal and external stakeholders? How have you changed your approach, standards/guidance, and/or process based on these surprises?

Appendix B: Biographies of Study Team Members

Connie Yew, P.E. (Study Team Lead), Team Leader for Construction Management, Federal Highway Administration

Connie Yew serves as Team Leader for Construction Management in the Federal Highway Administration (FHWA) Office of Infrastructure in Washington, DC. In this position, Ms. Yew leads key national efforts to advance innovative construction technologies, such as Unmanned Aerial Systems (UAS) and Building Information Modeling (BIM) for infrastructure. Since joining FHWA in 1983, she has held various leadership positions and helped strengthen FHWA's stewardship and oversight role in administering a $40 billion Highway program. Ms. Yew holds a Bachelor's degree in Civil Engineering from the University of Maryland and a Master degree in Public Administration from the George Washington University. Ms. Yew is a licensed Professional Engineer in the State of Maryland.

Katherine Petros, Team Leader for Infrastructure Analysis and Construction, Federal Highway Administration

Katherine Petros leads the Infrastructure Analysis and Construction Team within FHWA's Office of Infrastructure Research & Development at the Turner-Fairbank Highway Research Center. Her team is responsible for research and development activities focused on advancing construction and project delivery technology in addition to asset management, nondestructive evaluation and pavement performance prediction technology. Ms. Petros earned her Bachelor and Master of Science degrees in Civil Engineering from the University of Illinois at Urbana-Champaign.

Michael J. Kennerly, PE, Director of the Office of Design, Iowa Department of Transportation

Michael Kennerly is the Director of the Office of Design for the Iowa Department of Transportation. He has worked for the Department for 36 years, with 17 of those years in his current position. His previous experience includes working as Project Scheduling Engineer, Resident Maintenance Engineer, Detail Bridge Design Engineer, and as an EIT in the Des Moines Combined (Maintenance\Construction) Residency. Mr. Kennerly is a member of the AASHTO Subcommittee on Design and the recipient of the 2013 AASHTO Subcommittee on Design National Award. Mr. Kennerly has a Bachelor of Science degree in Civil Engineering, from the University of Iowa and is the proud grandfather of two.

April Blackburn, Acting Assistant Secretary of Finance and Administration and Chief of Transportation Technology, Florida Department of Transportation

April Blackburn is the Acting Assistant Secretary of Finance and Administration and the Chief of Transportation Technology at the Florida Department of Transportation (FDOT). With 29 years of experience in public sector IT, Ms. Blackburn has been involved in the development of the FDOT's

Technology Strategic Plan, Information Technology/Operational Technology (IT/OT) Alignment, and Civil Integrated Management. Ms. Blackburn served as FDOT's Chief Information Officer from May 2015 – September 2016. In September 2016, she was promoted to the position of Chief of Transportation Technology where she is responsible for IT/OT Alignment for the agency. In December 2017, Ms. Blackburn was asked to serve as the Acting Assistant Secretary of Finance and Administration where she is responsible for the delivery and the continuum of the Department's financial services to include planning, development, finance, administration, quality assurance, and quality control.

Roger Grant, Program Director, National Institute of Building Sciences

Roger J. Grant is a Program Director for the National Institute of Building Sciences (NIBS) where he manages projects for Federal agencies. He has focused on developing and delivering information products and services to support design, construction, and management of the built environment for more than 30 years. Mr. Grant has experience in whole building performance; building and civil infrastructure information modeling; safety and security assessment; cost planning and estimating; and technology, project, and business management. As a member of A-E-C Industry associations, he has been extensively involved in technology and standards development nationally and internationally. Mr. Grant began working with bSI shortly after its founding and is now the leader of the bSI Product Room. He holds a Bachelor of Science in Construction Management and a Masters of Business Administration both from Bradley University.

Jagannath Mallela (Study Report Facilitator), Senior Vice President and Director of Research and Innovation Solutions, WSP USA Inc.

Dr. Jagannath Mallela is a Senior Vice President at WSP and serves as the Director of the firm's Research and Innovation Solutions advisory practice. Dr. Mallela's vast body of technical work as an applied researcher or consultant on highway policy information and analysis, highway asset management, building information management and modeling, data governance in transport, automation in the highway construction sector, innovative infrastructure project and service delivery, organizational transformation, connected and integrated transportation systems, transportation economics, software development, and artificial intelligence. Dr. Mallela has conducted multiple Building Information Modeling (BIM) related research studies of national importance and has developed practical guidance to support BIM implementation. He is currently leading the development of FHWA's BIM for Infrastructure Strategic National Strategic Workplan and Data Governance Standard Framework for BIM implementation. He is also leading AASHTO's Standard Data Integration Framework Development and Deployment effort and FHWA's Applications for Enterprise GIS in Transportation efforts that involve working with several public transportation agencies across the US.

Appendix C: Host Organization Background Information

The Netherlands

Rijkswaterstaat

“Rijkswaterstaat is part of the Dutch Ministry of Infrastructure and Water Management and responsible for the design, construction, management, and maintenance of the main infrastructure facilities in the Netherlands. Within Rijkswaterstaat, the BIM program ensures the development and rollout of BIM and provides software tools, standards, models, testing, training, and guidance.”

BIMLoket

“BIM Loket is a virtual reference desk that ensures all BIM standards are open, accessible, reliable, and well-coordinated. The objectives of this organization are to:

- Promote the use of open BIM standards.
- Offer information to users.
- Jointly manage Dutch open BIM standards.
- Coordinate and strengthen national and international connections.
- Forge links between existing knowledge organizations.”

TNO

“TNO, the Netherlands Organisation for applied scientific research, was founded by law in 1932 to enable business and government to apply knowledge. TNO is independent and not part of any government, university, or company.

TNO develops open data standards and open source tools to support the merging of data and processes into a single collaborative process. The organization’s tools include BIMserver.org, the BIM protocol generator, the BIM Quickscan, BIM Quality blocks, and many more.”

Norway

Bane NOR

“Bane NOR is a State-owned company responsible for the national railway infrastructure. Bane NOR's mission is to ensure accessible railway infrastructure and efficient and user-friendly services, including the development of hubs and goods terminals. The company is responsible for the planning, development, administration, operation, and maintenance of the national railway network, traffic management, and administration and development of railway property. Bane NOR has operational coordination responsibility for safety work and operational responsibility for the coordination of emergency preparedness and crisis management.”

"Bane NOR has adopted a BIM strategy, which applies the following requirements to contractors:

1. Model-based methods and tools must be used for the planning, design and construction of all railway infrastructure projects.
2. "As built" documentation of completed projects must be model-based. There are requirements for model-based documentation from consultants, suppliers, and contractors. Bane NOR will own the rights to all project data throughout the process. It should also be possible to use the models or data for future operation and maintenance of the railway infrastructure.

The BIM strategy is based on the concept of using 3D models instead of traditional drawings and tables. During the construction phase, the model will be available at the site and will be actively used for monitoring quality, quantity control, progress, and communication."

Nordic Road and Rail BIM Collaboration
"The Nordic Road and Rail BIM Collaboration represents an agreement signed in October 2016 between public road and rail administration representatives from Denmark (Banedanmark and Vejdirektoratet), Finland (Finnish Transport Agency), Norway (Statens Vegvesen, Nye Veier & Bane NOR), and Sweden (Trafikverket). This group was established to exchange experiences using BIM and to influence international standardization."

buildingSMART Nordic
"buildingSMART Nordic consists of national buildingSMART organizations in Denmark, Finland, and Sweden. The vision of buildingSMART Nordic is "sustainability by building SMARTER." buildingSMART Nordic seeks to contribute to a sustainable built environment through SMARTER information sharing and communication using open international standards in the building and construction sector, private and public. It provides networking opportunities, specifications, and written guidance seeking to accelerate marketing assimilation of interoperability through a successful sustainable project."

buildingSMART Norway
"buildingSMART Norway is a neutral arena for innovation and digitization of the building, construction and property industries. The association works for smarter information sharing for a sustainable built environment. This makes the whole industry more profitable and resource-conscious. buildingSMART Norway works to identify the need for new open BIM standards to be created, nationally and internationally, which will make the industry pace and cooperate better and inform about resources and good examples of usage. buildingSMART Norway organizes the industry in professional user groups and in the Interdisciplinary User Forum that handles interdisciplinary issues."

United Kingdom

Centre for Digital Built Britain
"The Centre for Digital Built Britain is a partnership between the Department of Business, Energy & Industrial Strategy and the University of Cambridge to deliver a smart digital economy for infrastructure and construction for the future and transform the UK construction industry's approach to the way we

plan, build, maintain, and use our social and economic infrastructure.

The Center for Digital Built Britain (CDBB) is committed to supporting the adoption of BIM as business as usual and the evolution of the UK BIM Programme. While the existing BIM process, which supports the digital asset life-cycle, will continue to develop to keep up with advances in Digital Construction and smart asset management and operation, the Centre recommends moving away from the terms 'BIM Level 3 and BIM Level 4' to 'operate and integrate'. The Programme to date has shown that the shift beyond BIM is not linear in nature; it can be broadly defined as the change from the improved asset delivery and maintenance to the smart operation and performance of a portfolio of assets, which can be integrated to enable the optimization of organizational business services and socio-economic outcomes."

Appendix D: FTIA'S BIM Roadmap and Maturity Strategy

2019: 1 ½ | 2021: 2 - 3 | 2025: 3 +

	Level 0		Level 1	Level 2	Level 3		Level 4
Content	Pencil and ink lines, text.	Digital lines, text, blocks and symbols in 2D.	Simple 3D objects.	3D building objects with unspecified information	3D building objects with requirements to objects, properties and ID	Manufacturer's 3D objects & properties for operation /FM	All project, operational documentation and history are linked to objects in the model
Digitization	Drawings on transparent paper on a drawing table.	Drawings made with 2D CAD in a computer.	Drawings made with 3D CAD/BIM.	Drawings / views from BIM.	Drawings / views from BIM streamed to mobile devices. Limited paper use.	Open BIM with dimensioning streamed to mobile devices.	Open BIM with all operational information and history streamed to mobile devices.
Interoperability	Drawing on plastic fil copy of other disciplines drawings.	Work on 2D DWG or DXF background from other disciplines.	Work on 3D DWG background from other disciplines.	File based sharing of open BIM (IFC/inframodel), aggregated models hosted in the common data environment.	Server based sharing of open BIM (IFC), continuous validation of model.	Server based communication & issue handling, all issues related to objects in BIM.	Sensors enrichen model. Direct communication between the model and functional systems.
Collaboration	Coordination in design meetings and onsite meetings.	Systematic interdisciplinary controls with digital workflows.	3D visualization, visual controls in modeling tools.	Systematic model coordination, clash detection, quantity take off.	Interface handling in BIM. Advanced simulations. Integrated Project Delivery (IDP).	Models carry all information for construction and operation. Model driven production and assembly.	Model used by operations and for employees, users and the public.
Delivery method	Paper copies.	PDF/TIFF or paper copies.	PDF/TIFF or paper copies.	File based sharing of open BIM (IFC/inframodel). PDF or paper copies.	File based sharing of open BIM (IFC/inframodel). Sharing of combination models.	Automatic data transfer between phases, e.g. from construction to maintenance.	Continuous electronic data transfer in all project and business tasks.
Cost estimation	Assessed with traditional methods.	Cost estimation is not linked to the model.	Simple data reports from model, like mass quantities.	Cost estimation database.	Calculating life cycle costs from the model.	Models include all necessary cost information linked to other functions.	Cost estimation is a clear fifth dimension. (3D + 4D time + 5D).

5.

U.S. Department
of Transportation

**Federal Highway
Administration**