AS 7739.1:2022

Digital engineering for rail
Part 1: Concepts and principles

RISSB
RAIL INDUSTRY SAFETY AND STANDARDS BOARD

Infrastructure Standard

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This Australian Standard® AS 7739 Digital Engineering for Rail – Part 1: Concepts and Principles was prepared by a Rail Industry Safety and Standards Board (RISSB) Development Group consisting of representatives from the following organisations:

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The Standard was approved by the Development Group and the Enter Standing Committee Standing Committee in Select SC approval date. On Select Board approval date the RISSB Board approved the Standard for release.

Development of the Standard was undertaken in accordance with RISSB's accredited process. As part of the approval process, the Standing Committee verified that proper process was followed in developing the Standard

RISSB wishes to acknowledge the positive contribution of subject matter experts in the development of this Standard. Their efforts ranged from membership of the Development Group through to individuals providing comment on a draft of the Standard during the open review.

I commend this Standard to the Australasian rail industry as it represents industry good practice and has been developed through a rigorous process.

Deb Spring
Chief Executive Officer
Rail Industry Safety and Standards Board

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This Standard was prepared by the Rail Industry Safety and Standards Board (RISSB) Development Group AS 7739 Digital engineering for rail – Part 1: Concepts and principles Membership of this Development Group consisted of representatives from the organisations listed on the inside cover of this document

Objective

The objective of this Standard is to:

- build on current developments and progress with DE;
- combine globally leading practice;
- define contemporary best practice;
- specify building blocks for national consistency;
- reduce complexity for both asset owners and industry suppliers;
- provide a method for creating and classifying information relating to rail assets in a consistent manner;
- simplify the mapping of asset information by providing a consistent and repeatable information delivery method.

This Standard is Part 1 of the AS 7739 Digital Engineering for Rail series.

Part 1: Concepts and Principles

AS 7739 Part 1 provides DE guidance, that introduces and defines key concepts and principles for the ANZ rail industry. This guide provides detailed information on how to build data management capability, and the overarching digital framework required for successful DE project implementation.

It is not intended to be directly referenced in project procurement contracts, as it does not provide the appropriate level of detail necessary to adequately specify DE project deliverables.

Part 2: Technical Requirements

AS 7739 Part 2 provides detailed technical requirements (including specifications and procedures) for procurement and management of DE project deliverables.

Compliance

There are four types of provisions contained within Australian Standards developed by RISSB:

1. Requirements.
2. Recommendations.
3. Permissions.
4. Constraints.

Requirements – it is mandatory to follow all requirements to claim full compliance with the Standard. Requirements are identified within the text by the term 'shall'.

Recommendations – do not mention or exclude other possibilities but do offer the one that is preferred. Recommendations are identified within the text by the term 'should'.

Recommendations recognize that there could be limitations to the universal application of the control, i.e. the identified control is not able to be applied or other controls are more appropriate or better.

Permissions – conveys consent by providing an allowable option. Permissions are identified within the text by the term 'may'.

Constraints - provided by an external source such as legislation. Constraints are identified within the text by the term 'must'.

For compliance purposes, where a recommended control is not applied as written in the standard it could be incumbent on the adopter of the standard to demonstrate their actual method of controlling the risk as part of their WHS or Rail Safety National Law obligations. Similarly, it could also be incumbent on an adopter of the standard to demonstrate their method of controlling the risk to contracting entities, or interfacing organisations where the risk may be shared.

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Appendix Contents

1 Scope and general

1.1 Introduction

1.1.1 General

AS 7739 (all parts) provides information on best-practice digital engineering (DE), based on International Standards and leading digital initiatives from global organisations and Australian and New Zealand (ANZ) transport agencies.

This series aims to inform the ANZ rail industry by providing guidance, requirements, and recommendations for the use of DE in planning, design, and construction of rail infrastructure projects.

The AS 7739 series consists of two parts:

(a) Part 1: Concepts and principles (this Standard);

(b) Part 2: Technical requirements

The advice provided in this series builds on cross-sector digital innovation, established business processes, major infrastructure projects, and leading global sources. The resulting guidance defines how best to enable DE standardization throughout the ANZ rail industry.

Referring to Figure 1.1, AS 7739 (all parts) aims to provide nationally consistent:

(c) high-level advice for organisational strategies and planning;

(d) more informed guidance and managerial processes;

(e) detailed technical solutions and data specifications.

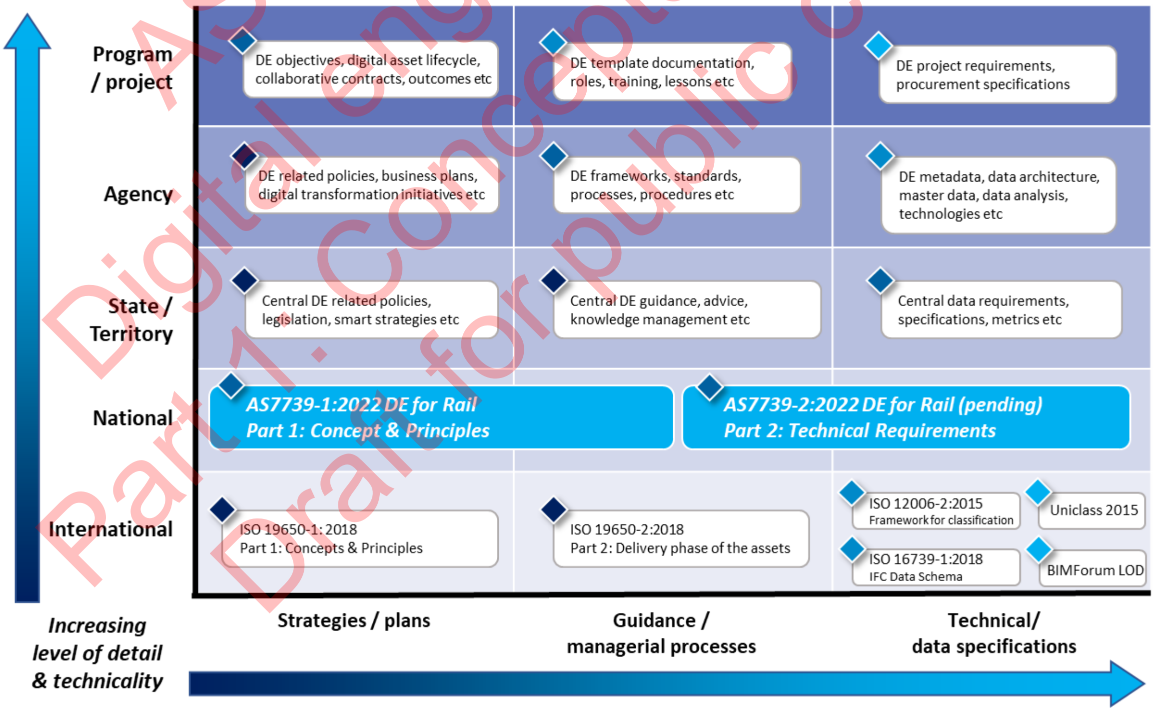


Figure 1.1: Landscape of DE standardization – from international guidance through to detailed project specifications

It is noted further detail and specification could be required at a state/territory, agency, and program level, to ensure suitable requirements are established for procurement and exchange of DE project deliverables.

1.1.2 International Standards

1.1.2.1 Overview

ISO 19650 is a suite of International Standards (published from 2018 onwards) that provides guidance on the use of building information modelling (BIM) to improve information management over the lifecycle of buildings and civil works. These standards elevated many of the concepts taken from the previous UK BS/PAS 1192 suite of standards (released between 2013-2018), to cater for a broader, more generic international audience.

In the context of ANZ rail industry, there has been a rapid uptake in the use of these standards, and they are now commonly regarded as global best practice for project and asset management. Client agencies at all levels of government are now commonly prescribing guidance and project deliverables in accordance with ISO 19650. It is worth noting, references to ISO 19650 were even included in the Infrastructure Australia 2021 Australian Infrastructure Plan (released Sept 2021), which demonstrates the high regard in which these standards are held.

Refer to Appendix B for an overview of the key concepts and processes defined in ISO 19650.

1.1.2.2 Digital maturity of ISO 19650

ISO 19650 Part 1 provides a three-stage maturity model, that denotes progress from analogue and digital information management. Stage 2 maturity, which represents a blend of manual and automated information management processes, is considered BIM according to the ISO 19650 series.

ISO 19650 does not provide any further details on:

(a) a roadmap or expected timeline to progress to Stage 3 maturity; or

(b) possible solutions to improve digital maturity beyond Stage 2.

Refer to Appendix C for current limitations of ISO 19650 Stage 2 digital maturity.

A summary of the digital maturity model is provided in Table 1.1.

Table 1.1: ISO 19650 digital maturity model

Digital Maturity	Stage 1	Stage 2	Stage 3
Information layer	Unstructured data	Unstructured data	Unstructured BIG data
	------------------------------------ Structured data ------------------------------------		
	-	Federated information models	Federated information models
	-	-	Object-based server information models
Technology layer	File/ Model/ Container	File/ Model/ Container	Database/ Query/ Model/ Container
	--------------------- Information management technology based ----------------- --------------------------- common data environment (CDE) ------------------------		
Standards layer	National Standards	ISO 19650 with Regional/ National Annexes	Process standards to be developed

Stage 3 presents a significant improvement from the current maturity level of ISO 19650, and offers a range of new digital capabilities such as:

(a) the introduction of big data;

(b) the introduction of object-based server information models, that provide further capability than current federated information models;

(c) a shift from "information containers" (otherwise known as file-based data management), to the use of databases and support for database queries;

(d) new digital standards that will enable further levels of process automation.

Collectively these new digital capabilities will enable a step change productivity, through improved data management methodologies, that will transform the way project and asset information is managed over the complete lifecycle.

In the context of the ANZ rail industry, pioneering work is currently underway to build more advanced ways of working that closely align with Stage 3 digital maturity. Leading ANZ transport organisations have commenced programs of innovation, and are already developing new digital processes and frameworks, trialling emerging technologies and building more advanced data management capabilities. In short, the ANZ rail industry is progressing rapidly, with digital standardization that extends well beyond the current stage 2 maturity of the ISO 19650 series.

The AS 7739 series builds on the foundations established in ISO 19650 and introduces more advanced data management concepts and principles that collectively define best practice DE for rail infrastructure.

1.1.3 Standardization of the ANZ rail industry

1.1.3.1 Background

DE offers a range of transformational benefits across the full asset lifecycle of rail infrastructure projects, through the use of digital technologies and optimized ways of working. DE techniques are now commonly applied on major rail infrastructure projects, realising immediate benefits such as improved design coordination, faster project delivery and less project variations.

That said, many of the benefits of DE have often been short-lived, hindered by inconsistent methodologies, a lack of interoperable data and generally low digital maturity. Furthermore, there has been little consideration for aligned digital processes over the full asset lifecycle, resulting in limited reliability or re-use of project information beyond single phases of the lifecycle.

Most importantly, there has been no agreed DE standards or guidance that define best practice across the ANZ rail industry. Rail agencies and asset owners have individually developed bespoke DE project requirements, with varying levels of detail and specification. This has made it challenging for industry to interpret and respond to a growing number of diverse DE terms, definitions, conventions, requirements and specifications.

It is now universally recognized by both the public and private sectors that an ad-hoc and siloed approach is not sustainable. There is a need for consistency, developed in partnership by the ANZ rail industry, to define and agree on a common approach to DE for rail infrastructure projects. Standardization will enable digital transformation and unlock a step-change in productivity throughout the rail infrastructure sector.

1.1.3.2 Current landscape

The ANZ rail industry is diverse, comprising numerous government bodies, asset owners and industry suppliers – all with varying levels of digital capability. Efforts to harmonize the uptake and implementation of DE across the ANZ rail industry should therefore recognize, and be developed in the context of, the current environment.

ISO 19650 provides a well-recognized foundation for national standardization. It is noted however that ISO 19650 is a global standard, and as such, it intentionally lacks technical detail and requires further levels of technical specification by clients prior to adoption or direct implementation of the standard.

In the context of the ANZ rail industry, there are numerous DE related initiatives currently inflight at a jurisdictional government or agency level. These initiatives are working at varying levels of detail, from high-level strategic programs, through to detailed data specifications and related technologies.

Furthermore each state and territory has their own legislations, contract models, project requirements and ways of working that could also influence DE strategies or detailed specifications.

1.1.3.3 The need for harmonization

The development of DE at a jurisdictional, agency and project level is accelerating throughout the ANZ rail industry. Key factors driving this change include the increasing industry capability, the rapid uptake of new technologies and the growing demand for data-driven insights on major rail infrastructure projects.

This trend of organic growth is likely to continue, and if left unchecked, could result in a diverse landscape of localized and incompatible DE solutions, that would require significant expense to harmonize at a later stage. It is for this reason industry commentators have often drawn comparisons with the operational challenges caused by numerous rail gauges throughout Australia.

There is now a clear need for national harmonization of DE initiatives across the ANZ rail industry.

National DE standardization provides the following benefits:

(a) Nationally consistent terms, definitions and conventions, thereby removing current ambiguities that restrict collaboration within the ANZ rail industry.

(b) Enables data sharing between rail projects, program, agencies and jurisdictions.

(c) Enables benchmarking and master data management across the ANZ rail industry.

(d) Reduces complexity for industry providers providing digital services to multiple ANZ rail infrastructure clients.

(e) Builds digital capabilities and attract new talent into the rail industry.

1.1.3.4 Role of AS 7739

The development of DE standards for the rail infrastructure sector is not starting from scratch. There are already pockets of excellence across ANZ and globally that can be adapted to help accelerate the development of National Standards. The AS 7739 series has been developed in collaboration with DE subject matter experts from the private and public sectors as well as academia. The resulting documentation builds on global standards, captures best practice from leading ANZ rail industry initiatives and is informed by recent project case studies.

1.2 Scope

This Standard provides a common baseline to establish a standardized approach for improved procurement, management, and exchange of project information deliverables through DE. This is aimed at improving digital collaboration between asset owners and their supply chains and promotes further digital transformation of the ANZ rail industry.

AS 7739 (all parts) covers fixed rail infrastructure (e.g. building and civils works) only.

The scope of AS 7739 (all parts) covers the overarching principles, data management processes and technical requirements, to define good practice DE for key project information deliverables including (but not limited to):

(a) survey;

(a) laser scanning;

(b) computer aided design (CAD);

(c) building information modelling (BIM);

(d) geographic information systems (GIS);

(e) documentation.

The scope of this Standard covers fixed rail infrastructure (e.g. building and civils works) only. This includes structural elements required to support rail systems (e.g. pits, pipes, huts, combined services route (CSR), overhead wiring (OHW) structures, etc).

1.3 Exclusions

DE applications and technologies that are outside the scope of this Standard include:

(a) blockchain;

(b) advanced building materials;

(c) pre-fabrication and modular construction;

(d) 3D printing and additive manufacturing;

(e) autonomous construction;

(f) augmented reality;

(g) big data and predictive analysis;

(h) internet of things, remote sensors, fog/cloud computing and smart infrastructure;

(i) real time collaboration.

Rail specific elements that involve detailed circuits and safety critical systems are currently outside the scope of this Standard. This includes techniques for modelling and management of rail systems relating to the following engineering disciplines:

(j) Signalling.

(k) Communications.

(l) High voltage / low voltage power.

(m) Overhead wiring.

(n) Earthing & bonding.

The operations and maintenance (O&M) phase of the asset lifecycle is intentionally excluded in this release due to significant technical complexities associated with transforming current practices and commercial challenges with varying long-term contracts with existing enterprise asset management systems.

Fleet / rolling stock is excluded due to comparative differences between construction and manufacturing of fleet vehicles

1.4 Structure of this Standard

AS 7739.1 comprises a number of key topics as follows:

(a) DE key concepts – General background, concepts and advice on DE and data management.

(b) DE business setup – Business improvements required prior to procurement and implementation of DE on rail infrastructure projects.

(c) DE project planning – Activities required for DE scoping and specification in project contracts, to inform procurement of DE services.

(d) DE project delivery – Activities required for successful delivery of DE services for rail infrastructure projects.

This Standard covers three specific subjects for each of the key topics, as presented in Table 1.2. The table also identifies the primary audience (or action owner) for each of the subjects, that include either the asset owner, the delivery partner or all stakeholders.

Table 1.2: Structure of AS 7739 Part 1

Key topic	Subject	Primary audience	Standard section
DE key concepts	1. Data management	All	2
	2. Metadata to support DE	All	3
	3. Data modelling to support DE	All	4
DE business setup	4. Conceptual data Model for DE	Asset owner	5
	5. Introduction to master data entities	Asset owner	
	6. Introduction to general / specialist entities	Asset owner	
DE project planning	7. Project scope	Asset owner	6
	8. Project datasets	Asset owner	
	9. Project data models	Asset owner	
DE project delivery	10. Project procurement	All	7
	11. Digital project deliverables	Delivery partner	
	12. Structured datasets	All	

It is important to note that the primary audience for most of these subjects is the asset owner, given their central role in specification, procurement, and long-term management of DE deliverables. See overpage to Figure 1.2 for a more visual summary of the document structure.

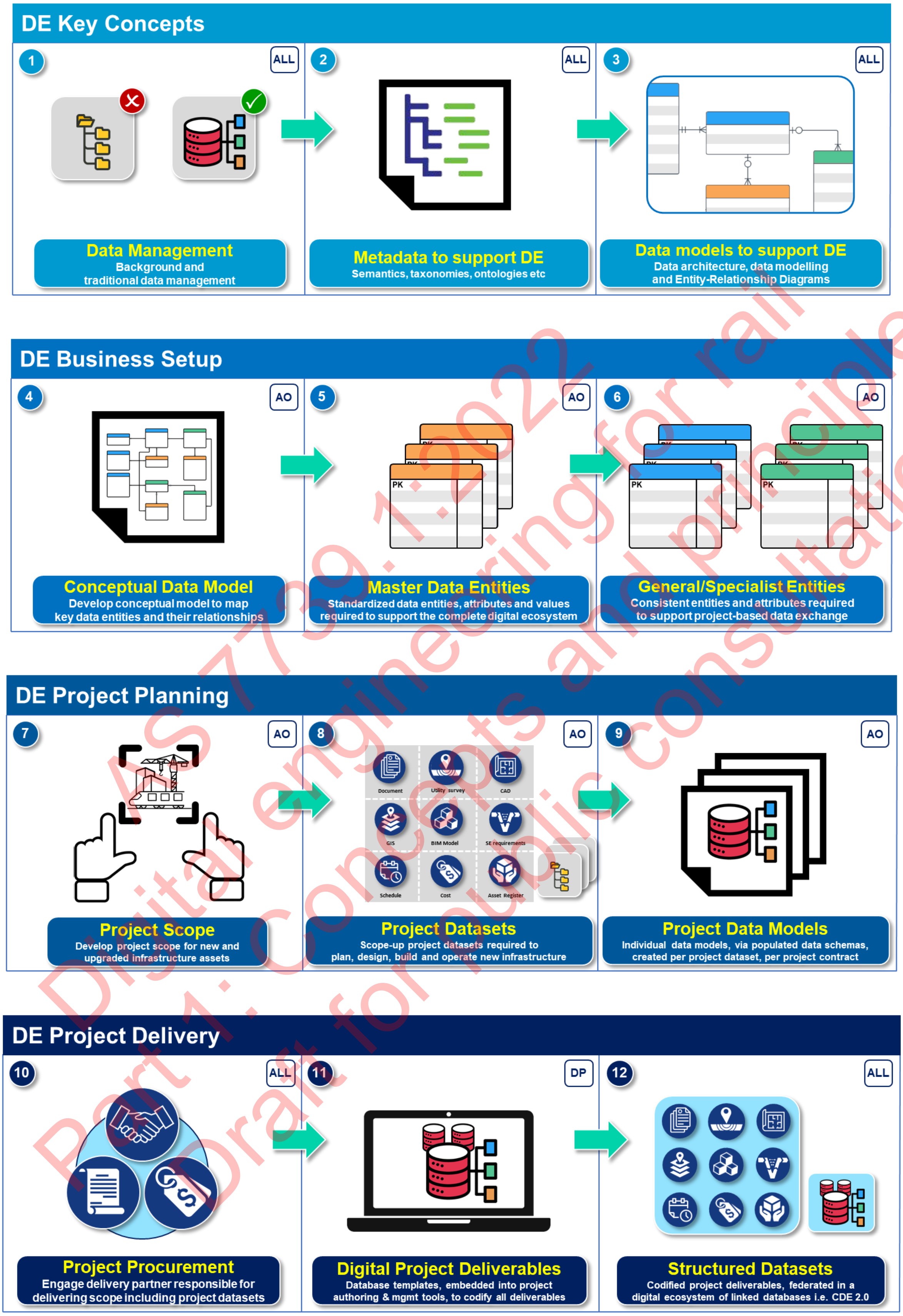


Figure 1.2: Business process required to establish DE

A further breakdown of the standards content is provided in Table 1.3.

Table 1.3: Contents of AS 7739 Part 1

Subject		Details
1	**Background on data management**	**Primary Audience:** All stakeholders **Role(s):** All roles **Standard Section:** 2 **Summary:** Background and traditional data management **Details:** Background and traditional data management, thinking beyond BIM What is DE? How does DE work? principles and benefits
2	**Metadata to support DE**	**Primary Audience:** All stakeholders **Role(s):** All roles **Standard Section:** 3 **Summary:** Metadata, semantic interoperability and asset classification **Details:** Semantics (taxonomies and ontologies), asset classification, ISO 12006.2 and Uniclass 2015
3	**Data models to support DE**	**Primary Audience:** All stakeholders **Role(s):** All roles **Standard Section:** 4 **Summary:** Data architecture, data modelling and entity-relationship diagrams (ERD). **Details:** Data modelling concepts, terminologies and notations, Entity-Relationship Modelling, Conceptual / logical / physical models
4	**Conceptual data model**	**Primary Audience:** Asset owner **Role(s):** DE developer(s) **Standard Section:** 5 **Summary:**

		Develop conceptual model to map key data entities and their relationships **Details:** Build a comprehensive ERD using a standardized form of data modelling notation (e.g., crow's foot) to identify and map key data groups, entities, identifiers, attributes, and relationships. Data entities may be categorized by the following types: Master data – Data libraries relevant to all projects General entities – Relevant to all datasets on a single project Specialized entities – Relevant to specific datasets
5	**Master data entities**	**Primary Audience:** Asset owner **Role:** DE developer(s) **Standard Section:** 5 **Summary:** Standardized data entities, attributes and values required to support the complete digital ecosystem. **Details:** Compile libraries of master data (including both primary keys and associated attributes) to provide consistent entities for project/asset data. All master data shall be machine readable, to enable automated data exchange and re-use for all parties throughout the digital ecosystem, over the complete asset lifecycle.
6	**General / specialist entities**	**Primary Audience:** Asset owner **Role:** DE developer(s) **Standard Section:** 5 **Summary:** Consistent entities and attributes required to support project-based data exchange. **Details:** Develop consistent database templates specific to each type of project dataset. Schemas will comprise both general and specialized data fields, based on the specific requirements for each type of dataset.
7	**Project scope**	**Primary Audience:** Asset owner **Role:** Project team **Standard Section:** 6 **Summary:** Define project scope, based on operational plans, systems engineering methodologies (including business and system requirements) and business case approval processes.

		Details: Define project scope, based on operational plans, systems engineering methodologies (including business and system requirements) and business case approval processes.
8	**Project datasets**	**Primary Audience:** Asset owner **Role:** Project team & DE manager(s) **Standard Section:** 7 **Summary:** Scope-up information deliverables (i.e. project datasets), that are necessary to plan, design and build physical infrastructure. This exercise should consider opportunities for data sharing, re-use and federation, to maximize benefits and opportunities with key project datasets. **Details:** Scope-up information deliverables (i.e. project datasets), that are necessary to plan, design and build physical infrastructure. This exercise should consider opportunities for data sharing, re-use and federation, to maximize benefits and opportunities with key project datasets.
9	**Project data models**	**Primary Audience:** Asset owner **Role:** DE manager(s) **Standard Section:** 8 **Summary:** Individual data models, via populated data schemas, created per project dataset, per project contract **Details:** Develop bespoke database schemas (i.e. data models), that are created specifically per project dataset, per project contract. These essentially pre-populate the data schema tables with known metadata, specific to each project, to form the 'project data schemas' (PDS). These are typically developed by the project client prior to commencing procurement, and form part of the tender documentation for the tenderers to assess and respond.
10	**Project procurement**	**Primary Audience:** Asset owner **Role:** Project team & DE manager(s) **Standard Section:** 9 **Summary:** Engage delivery partner responsible for delivering scope including project datasets **Details:** Upon completion of the procurement process, further work could be required to update and / or revise the PDS with the winning tenderer.

		Once final changes are formally agreed, the PDS for each form of dataset is essentially locked in place, to ensure all metadata is controlled going forward.
11	**Digital project deliverables**	**Primary Audience:** Delivery partner **Role:** Digital engineer(s) **Standard Section:** 9 **Summary:** Database templates, embedded into project authoring & management tools, to codify all deliverables **Details:** The project partner (e.g. designer, builder etc) is to install the agreed PDS into their project authoring & data management tools. The project teams are then to tag all subsequent project deliverables with the PDS, to ensure correct metadata is applied to all respective project datasets.
12	**Structured Datasets**	**Primary Audience:** Asset owner & delivery partner **Role:** DE manager & digital engineer(s) **Standard Section:** 9 **Summary:** Codified project deliverables, federated in a digital ecosystem of linked databases i.e. CDE 2.0 **Details:** The delivery partner submits all project deliverables as structured datasets, that are able to be federated within the project CDE. Structured data is now available as a key resource for all permitted stakeholders, enabling data-driven decisions and insights by all relevant parties.

1.5 Normative references

There are no normative references in this document.

NOTE: Documents for informative purposes are listed in Appendix D.

1.6 Terms and definitions

For the purposes of this document, the following terms and definitions apply:

1.6.1
asset
item, object or entity that has potential or actual value to an organization

1.6.2
attribute
characteristics or properties of an entity

1.6.3
Building Information Modelling

BIM
process of designing and constructing a building or infrastructure asset using object-based 3D modelling

1.6.4
classification
see taxonomy

1.6.5
computer aided design
CAD
digital 2D or 3D drawings that replicate manual drafting techniques. This often involves using disconnected drawings that are manually drafted using lines, arcs and circles, which are then overlaid and coordinated in two dimensions

1.6.6
common data environment
CDE
agreed source of information for any given project or asset, for collecting, managing and disseminating each information container through a managed process

1.6.7
connected digital ecosystem
CDE 2.0
digital ecosystem of linked databases, that manages and exchanges datasets & metadata, using consistently structured data architecture, to ensure semantic interoperability over the asset lifecycle

1.6.8
constraint
restriction placed on data, usually expressed in the form of business rules e.g. “Quality rating needs to be between 0 and 5 stars.”

1.6.9
data model
a model of the users' data requirements, usually expressed in terms of the entity-relationship model

1.6.10
data modelling
process of creating a specific data model for a determined problem domain.

1.6.11
data schema
logical blueprint of how a database is constructed e.g. tables, relationships, indexes, views etc

1.6.12
database
shared, integrated platform that stores an organized collection of related data.

1.6.13
database management system
DBMS
computer software program used to manage and query a database.

1.6.14
database query
request to access or manipulate data from a database table or combination of tables, typically performed using Structured Query Language (SQL).

1.6.15
dataset
container or collection of data, that can be manipulated as a single unit

1.6.16
digital engineering
DE
a collaborative way of working, using semantic data management, to enable more productive methods of project delivery and asset management.

1.6.17
entity
any real-world 'thing' that can have data stored about it

1.6.18
foreign key
attribute that references a primary key from another entity, thereby linking two entities

1.6.19
geographic information system
GIS
spatial system that creates, manages, analyzes and maps all types of data

1.6.20
Industry Foundation Classes
IFC
specification for open BIM to support an open standard for information exchange, that is maintained by Building SMART International

1.6.21
information container
named persistent set of information retrievable from within a file, system, or application storage

1.6.22
information management
tasks and procedures applied to in-putting, processing and generation activities to ensure accuracy and integrity of information

1.6.23
information model
data set comprising of documentation, geometrical (graphical) and non-geometrical (non-graphical) data. Information Models are linked together using a common data structure (schemas) and classification system.

1.6.24
metadata
data about data that enables datasets to be structured, managed and federated

1.6.25
ontology
process of defining relationships between objects, systems and concepts

1.6.26
primary key
attribute that uniquely identifies an instance of the entity

1.6.27
relationship
dependency or association between two entities

1.6.28
semantics
systematic organization of data using consistent conventions, to reliably transfer information (e.g. context, meaning and relationships) about objects between parties

1.6.29
semantic data management
range of techniques that can be employed for storing, querying, manipulating, and integrating data based on its meaning

1.6.30
semantic interoperability
ability for computer systems to unambiguously exchange and federate data with universal meaning

1.6.31
Structured Query Language
SQL
dominant, standardised database language, used to define, control, manipulate and access relational data, stored in a DBMS

1.6.32
taxonomy
process of arranging objects into meaningful groups by class, using “type-of” relationships

General rail industry terms and definitions are maintained in the RISSB Glossary:
https://www.rissb.com.au/products/glossary/

1.7 Abbreviations

(a) ANZ
Australia and New Zealand

(b) CSR
combined services route

(c) CBS
cost breakdown structure

(d) ICT
information and communication technology

(e) OHW
overhead wiring

(f) SE
systems engineering

(g) WBS
work breakdown structure

2 Digital engineering concepts

2.1 Background

2.1.1 Traditional information management

In recent years there have been numerous studies researching the performance of transport infrastructure projects and the causes of time and cost overruns that impact successful project delivery. An overarching theme identified throughout these studies was the frequent nature of overruns during project delivery, with larger projects failing more frequently and with greater relative overruns.

A common finding from this research has identified that scope change as the leading cause of project variations and budget overruns, which is commonly linked with information management on construction projects.

Table 2.1: Challenges with traditional information management in the construction sector

Issue	Detail
Document-based	Project information is created in reports, and stored in segregated systems across a range of document management platforms
Disconnected	Created with-in siloed business units, with little consideration for consumption of information down the chain
Manual	Heavily administrative, with little consideration for process automation or information re-use
Ad-hoc	Projects are delivered inconsistently, with variable processes applied across the range of delivery programs
Subjective	Reliant on the personal knowledge, experience and relationships of individuals
Non-repeatable	Projects are delivered as though they are “one-off prototypes” with little consideration for creation of reliable, re-useable asset information or knowledge

Poor information management is now recognized to be a leading cause of overruns on construction projects, and is a frequent trigger for scope change, unforeseen errors and project delays. Table 2.1 above lists some of the more common issues with information management, that are observed universally on construction and infrastructure projects around the world.

2.1.2 Traditional data management

Traditionally on rail infrastructure projects, project information deliverables are developed by numerous parties, working independently, using siloed processes with discrete project breakdown structures and unique coding for all subsequent project deliverables.

For example:

(a) work breakdown structure (WBS) developed for the project schedule;

(b) cost breakdown structures (CBS) developed for the project cost estimate;

(c) design packages developed by the engineering teams;

(d) work packages created by the construction teams etc.

Project information deliverables within each project are therefore typically discrete, with little consideration for process interoperability or re-use by other downstream parties, at later stages of the asset lifecycle.

Furthermore, there has been little regard for how data within project deliverables could be associated across multiple project disciplines, or across multiple projects to enable an enterprise or portfolio view. Any attempts to build insights on across projects based on specific attributes (e.g. asset type, system components, asset location, delivery teams etc) has therefore been challenging and often required heavily manual processes.

Table 2.2: Issues with poor data management

Risk	Cause	Consequence
Data loss between stages	Insufficient contract specification of data deliverables	Less informed decisions, slower ramp up and recreation of deliverables required
Discovery of issues during construction	Poor visibility of interfaces between design packages and construction staging	Delays on site, disruptions to delivery, and increased variations
Stakeholder issues	Poor visibility and communication of project scope and construction impacts	Miscommunication of work on site. Stakeholder resistance and loss of reputation
Cost blow-out	Unforeseen changes due to unclear scope, design errors, insufficient coordination, unplanned works etc	Rework, scope changes, cost variations
Maintainer receives insufficient data	Information does not exist, is not handed over in a structured way or is unreliable	Additional cost and effort to capture asset data, manual process for asset data capture

2.1.3 The need for structured data

To address these issues, digital ways of working are now emerging in the construction sector that aim to improve project controls, enable greater cost certainty and deliver a step-change in project delivery.

This is transforming the way project and asset information is managed, through the adoption of emerging digital technologies and new business processes, that create cost savings and improve productivity for both contractor and client stakeholders. By structuring project data consistently, it can be reliably re-used by all project stakeholders to make more informed, data-driven decisions throughout the project lifecycle.

The digital transformation of the construction sector has been steadily accelerating over the past 20 years, which is largely due to the UK government's commitment to Building Information

Modelling (BIM), announced formally in the UK Government Construction Strategy in 2011. This policy sets a new direction for industry, and was a catalyst for new ways of working such as:

(a) defined information requirements over traditional project specifications;

(b) digital deliverables over paper documentation;

(c) model-based 3D design over 2D drawings;

(d) structured data over ad-hoc file structures;

(e) client leadership over supplier direction.

In the time since then, BIM is now rapidly becoming business-as-usual on major infrastructure project globally however the uptake of BIM is still largely being led by industry suppliers instead of the client organizations. BIM in isolation provides project benefits, however for it to be truly adopted by clients, it should be integrated with many other project datasets and then transformed to become digital.

2.2 Thinking beyond BIM

2.2.1 The evolution of design

BIM is now a common term in the rail infrastructure sector however there is still much uncertainty around a clear definition of what is BIM.

ISO 19650 defines BIM as the use of a shared digital representation of a built asset to facilitate design, construction and operation processes to form a reliable basis for decisions. This definition is intentionally ambiguous to serve the broadest range of assets, organizations, cultures and appointment roles.

This formal definition is relatively conceptual, as it does not establish any specific conventions, boundaries or limitations of BIM. Users could be correct in assuming that the process of BIM involves the production of geometric or object-based 3D modelling, however the standard does not make any clear association with these elements. The definition of BIM is effectively open to interpretation, and further clarity is required for to assist user understanding for the ANZ rail industry.

A simpler way to understand BIM is to consider how the design and delivery of buildings and infrastructure has evolved over the past 30 years. Refer to Figure 2.1, the design process has generally evolved through the following key deliverables:

(a) 2D geometric drawings – initially manually and then electronically through the introduction of computer-aided design (CAD) to represent 2D and 3D geometries.

(b) 3D geometric models – for visualization and improved stakeholder engagement.

(c) 3D “BIM” Models – 3D ‘object-based’ (or ‘smart’) 3D models enriched with linked data to enable BIM-centric outputs often described by dimension e.g. 3D, 4D, 5D, BIM.

(d) DE – enabling an ecosystem of linked databases based on consistently structured datasets and machine-readable metadata.

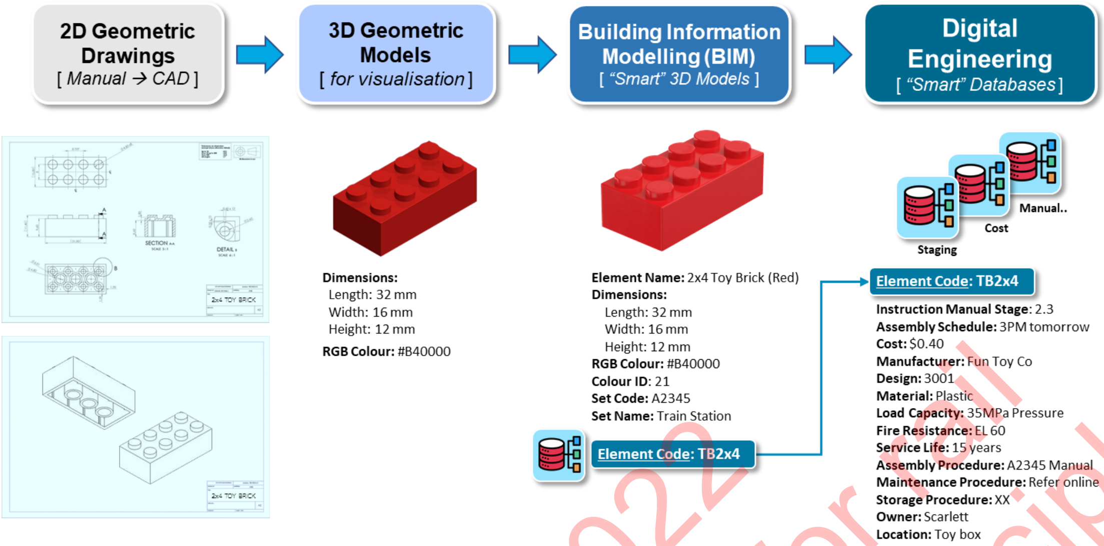


Figure 2.1: The evolution of design processes

The emergence of BIM has provided new, more visual ways of working, that have significantly improved the design coordination and information management. BIM-centric concepts such as 4D BIM (i.e. 3D BIM Model + project schedule) or 5D BIM (3D BIM model + cost breakdown) have been adopted by industry to describe new capabilities, develop new methodologies and achieve smarter design outcomes.

2.2.2 The evolution beyond BIM

Over the past 10 years BIM has proven to be a significant catalyst for technological change and has unlocked substantial productivity improvements for industry and asset owners. Outside of the direct benefits however, BIM in isolation has been unable to achieve broader digital transformation as many have expected. This has resulted in BIM remaining disconnected from other key datasets, lifecycle stages and business processes.

Industry experience has now shown that BIM-centric processes and terminologies have the potential to limit opportunities for broader integration outside specific use-cases. This can serve to hinder the opportunity for automated business integration, federation across a portfolio of projects or reliable re-use through the asset lifecycle.

More progressive organizations are now starting to think beyond BIM and are considering BIM models as a dataset in the context of a broader ecosystem of project datasets. This requires a new approach to data management, that enables numerous datasets from many sources to be automatically associated through structured, machine-readable data.

Digital engineering is the next step in this evolution.

2.3 What is digital engineering?

DE is defined as a collaborative way of working, using semantic data management, to enable more productive methods of project delivery and asset management.

DE creates data models that represent all aspects of physical infrastructure and support all activities over the complete asset lifecycle. These models use consistent data architecture with semantic interoperability, to ensure all datasets are machine-readable, and can be managed, exchanged, federated, and re-used in an ecosystem of linked databases. DE enables data integration across all stakeholders, creating a digital thread, supporting process automation, and allowing data to be managed more effectively as an asset.

Represented in Figure 2.2, DE brings together the complete ecosystem of deliverables that are created over the course of project delivery.

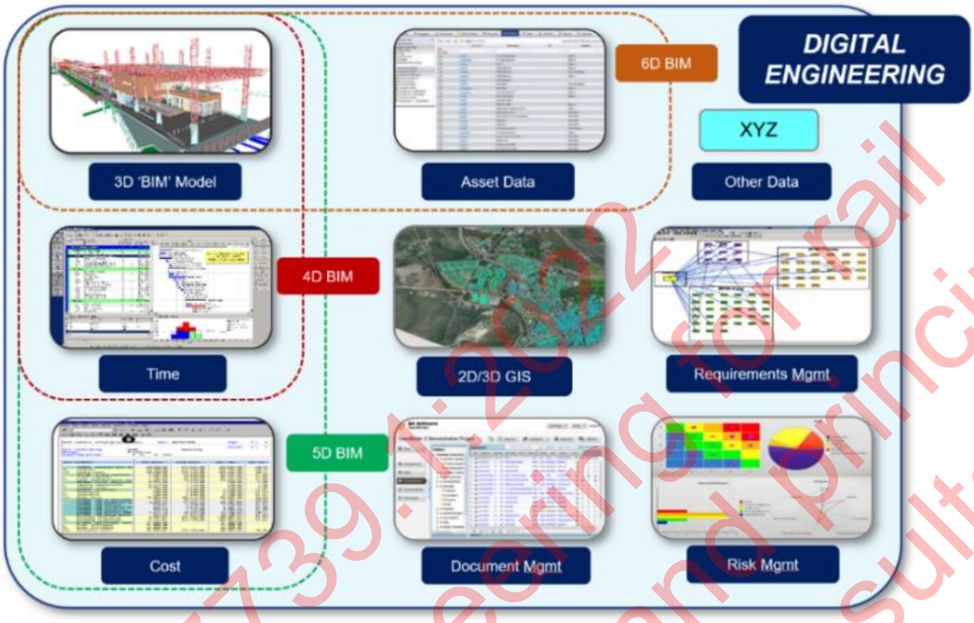


Figure 2.2: Digital Engineering – an ecosystem of digital project deliverables

Key project datasets include, but are not limited to, the following:

(a) Site surveys of above and below-ground features (inc. utilities).

(b) Geotechnical surveys.

(c) 3D point clouds (if laser scanning is undertaken on the project).

(d) Documents (e.g. design reports, construction certification, operational readiness documentation etc).

(e) 2D CAD drawings.

(f) 3D Building Information Models – otherwise known as BIM models.

(g) Geographic Information Systems (GIS) databases.

(h) Project schedules.

(i) Cost estimates.

(j) Project registers, including (but not limited to):

i. requirements registers (for systems engineering);

ii. asset registers;

iii. risk registers;

iv. safety registers;

v. defects registers etc.

Traditionally in the construction sector, datasets have typically remained siloed, due to a file-based approach to data management. Furthermore, the metadata associated with each type of dataset has been developed in isolation, with no consideration for interoperability or automated linkage across disciplines.

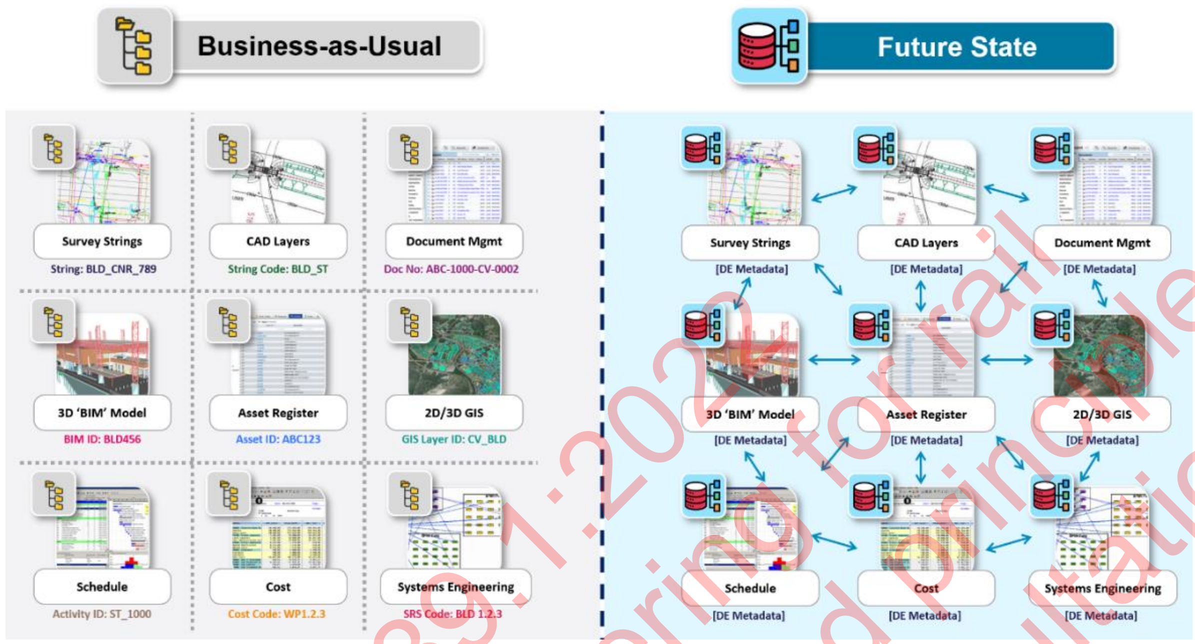


Figure 2.3: Transition from siloed electronic files to a digital ecosystem of linked databases

Referring above to Figure 2.3, DE works to address these siloes, by defining consistent metadata for all datasets, and effectively supports the digital ecosystem of linked databases.

The benefits of DE are wide-ranging, across broad range of use-cases, stakeholders and lifecycle stages. Some of the key benefits provided in Appendix A of this Standard.

2.4 Principles for digital engineering

DE provides a range of new business outcomes, that can be grouped into general principles as shown in Table 2.3. This list of 12 key principles has been developed based on in-depth research of 10 government led digital transformation programs from across ANZ and the UK.

Table 2.3: Principles for DE

No.	Theme	Principle	Details
1	Interoperability	Adopt open and interoperable formats (where possible)	To ensure data is consistent, flexible and scalable, and will maximize possible use-cases, applications and technologies (both current and future)
2	Governance	Actively manage and promote data custodianship	Through clearly defined owners, authority, responsibility, governance and regulation
3	Quality	Specify data with defined quality requirements	That allows users to derive meaningful insights and make more informed 'data-driven' decisions,

			by ensuring data is accurate, comparable, verifiable, fit-for-purpose and complete
4	Value	Manage data as an asset	Through mature digital capability and business integration, to realise benefits such as 'return-on-investment', ongoing business value, process improvement and public good
5	Collaboration	Enable digital collaboration and data federation	By creating an open ecosystem of interconnected and consistently managed databases
6	Capability	Normalize data literacy and foster digital dexterity	Through appropriate roles and resources, knowledge sharing and continuous improvement of business capability
7	Re-use	Maximize opportunities for data re-use	By producing datasets that are verifiable with transparent and preferably automated assurance processes, to avoid single use or uncesssary duplication
8	Secure	Protect the digital ecosystem	Through secure systems and controls that provide role-based access, traceability and real-time monitoring (with particular focus on data deemed to be safety critical, personal, confidential, classified and/or commerical in confidence)
9	Trust	Instil trust and confidence in data quality	By assigning primary sources for all shared datasets, including ownership, provenance and status
10	Accessibility	Enable data accessibility	Through platforms that support input, sharing and federation, from multiple physical locations
11	Automation	Eliminate or minimize manual data manipulation	Using more automated processes to create, manage and exchange shared data
12	Visualization	Create datasets that enable visualization	Using methods such as object-based modelling, spatial data or other related means, to support interrogation, association, interaction and collective understanding

2.5 How does digital engineering work?

DE enables effective data management, by creating digital project deliverables in open formats and tagged with standardised metadata (such as asset classification), to ensure semantic interoperability across all project disciplines.

Table 2.4 Key Enablers for digital engineering

Enabler	Details	Examples
Open data formats	Non-proprietary files formats to enable open exchange and federation of project datasets	• BIM - .ifc • Office - .docx, .xlsx, .csv • Documents - .pdf, .txt • Images - .jpg, .png
Metadata	Common semantics (taxonomy, ontology and schemas) to enable interoperability between parties over lifecycle	• Asset/location classification such as Uniclass 2015 • CAD - Drawing title block and line types • BIM - Object tagging • Cost – CBS such as ICMS Framework • Asset data - Product data sheets
Connected digital ecosystem (CDE 2.0)	A digital ecosystem of linked databases, that manages and exchanges datasets & metadata, using consistently structured data architecture, to ensure semantic interoperability over the asset lifecycle	• Multi-disciplinary infrastructure projects • Asset management platforms • Digital twin ecosystem

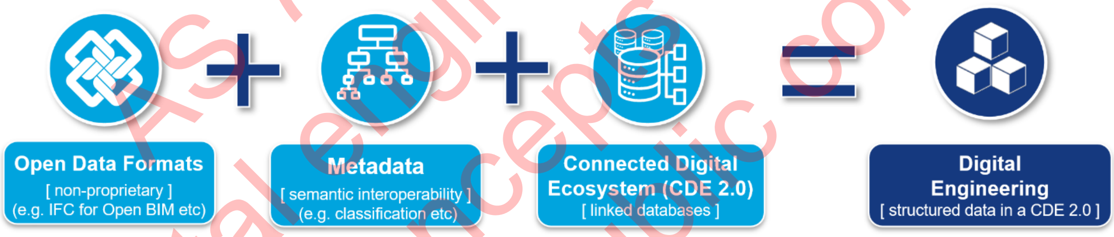


Figure 2.4: Key Enablers for Digital Engineering

This approach provides context to datasets and enables connected business processes through structured data. DE ensures all project datasets are procured, created, managed, and exchanged consistently in a digital ecosystem of databases – otherwise known as the connected digital ecosystem (CDE 2.0)

Structured data from across project deliverables can be easily recalled based on attributes such as:

(a) specific assets;

(b) asset systems;

(c) asset locations;

(d) project lifecycle stage;

(e) responsible parties.

DE therefore enables projects to easily recall information, associate data and gain critical insights on specific assets, multidisciplinary projects, multi-stage programs or even overall infrastructure networks.

It is important to note that most of the technology already exists. The concepts articulated above are not necessarily new to industry and have now been proven globally on large-scale transport infrastructure projects.

DE recognizes the importance of maintaining project specific datasets within their respective specialist software platforms. It aims to redefine the data structure of each deliverable, by improving metadata schemas and master data management of the deliverables, while remaining within the specialist software platforms or databases. This essentially defines the key principle of the CDE 2.0.

2.6 Data management

2.6.1 General

While BIM has been the catalyst for change, the more significant and transformative developments have been focussed on building data management capability. Data management is a critical component for all sectors, with most modern organizations now proactively managing data as an asset.

2.6.2 Historic file management

Traditionally organizations have procured information as files and records, with data stored and managed in siloed systems. Data has typically been created for single-use purposes only, with little-to-no consideration for how it could provide benefit to other parties or how it could be re-used to support business decisions over the full asset lifecycle. Furthermore, the storage of data in segregated or siloed systems has also impacted the ability for others to find records, limiting the ability for data to be accessed, associated or re-purposed for value-add business activities.

Most importantly, this approach does not permit data to be properly managed as asset, and limits potential opportunities for further value to be unlocked across an organization or over the full asset lifecycle.

2.6.3 Evolution to modern data management

The digital approach to data management moves away from single-purpose or project-centric information records. Progressive organizations are now focussing their attention on re-designing their data structures, to enable data to be managed in 'business-centric' database systems, as represented in Figure 2.5.

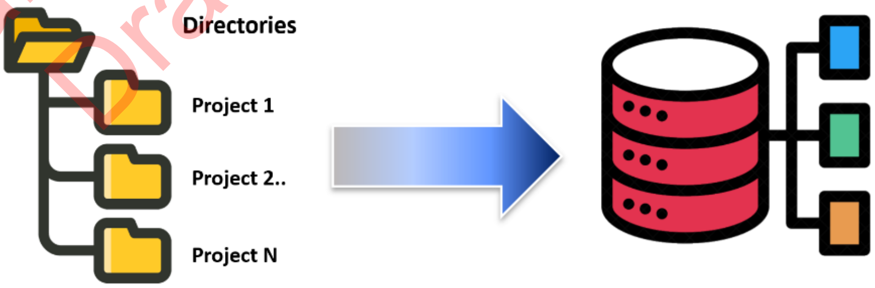


Figure 2.5 Transition from Directories to Databases

The aim of modern data management is to create or procure datasets to meet specific business requirements, using consistent processes, that are managed in standardized databases. A comparison between the two methodologies is provided in Table 2.5.

This high-level of prescription ensures that all datasets are structured, interoperable comparable and verifiable. Most importantly, all data is now managed as an asset, so that it is accessible and supports reliable re-use by all approved parties over the full asset lifecycle, thereby maximising the on-going value to the business.

Table 2.5: Comparison of file-based data management and database management

Attribute	File-based data management	Database management
Usage	Project-centric records with discrete rules and proprietary formats	Business-centric data with consistently defined attributes and open formats
Storage	Deliverables stored in file-based systems using ad-hoc processes	Data stored in consistently structured and managed database(s)
Purpose	Created to support single phase activities only (e.g. construction)	Created to support whole-of-life and whole-of-business activities
Characteristics	Siloed, uncontrolled, unsecure, unstructured, unrelated, inaccessible	Connected, controlled, secure, structured, related, accessible
Capabilities	Subjective, unverifiable, unreliable and little consideration for re-use	Objective, comparable, verifiable and reliable to maximize re-use

The traditional approach to data management greatly reduces the benefit and value of data and restricts the ability for organizations to collectively make more informed, data-driven decisions. Much of the value gained in project data is lost at handover, as projects transition from one stage to the next, due to discontinuity of data management, a lack of consistent data requirements and generally a lack of reliability and trust, as represented in Figure 2.6.

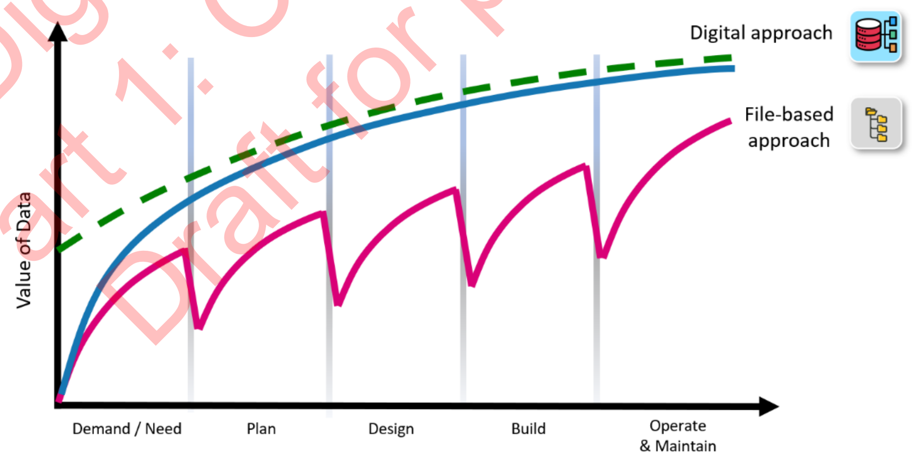


Figure 2.6 Value of data over the lifecycle

As a further extension, organizations with a digital approach to data management are no longer required to start from scratch at the commencement of new projects. Existing datasets can be accessed for reliable re-use and may be utilized to inform the initial stages such as planning, site investigation or modelling. This reduces the upfront effort that is traditionally required on projects, therefore unlocking further business value over the lifecycle.

2.6.4 Managing data and metadata

File-based management of project information, stored in siloed systems, is no longer suitable to support infrastructure projects and should be replaced with a more strategic, data-centric approach. The future of information management in the infrastructure sector should be end-to-end digital.

New skills are required that extend well beyond than the procurement of project BIM models or the introduction of new technologies such as cloud storage or laser scanning. The ANZ rail industry should become adept at not only managing project deliverables as datasets.

The sector should also build data literacy and become experts at managing the data about the data – otherwise known as metadata.

Figure 2.7 Evolution from documents to metadata management

2.7 Thinking beyond the common data environment

2.7.1 The common data environment

A core element of BIM is the setup of a common data environment (CDE) as the method of managing and exchanging project asset data. This term is commonly used in industry however it is also fairly ambiguous and is often misunderstood.

It can be assumed that the CDE represents a central repository or single source of truth for project information that it is supported by cloud-based enterprise content management (ECM) or document collaboration software. It could also be interpreted as a federation of systems, that provides a single view of truth across multiple information storage platforms, and brings combines datasets of numerous sources beyond typical BIM deliverables, such as schedule, cost estimates, systems engineering etc.

Referring to Figure 2.8, this provides some of the many diagrammatic representations of the CDE from numerous industry sources.

Figure 2.8: Diagrammatic representations of the CDE

ISO 19650 defines the CDE as agreed source of information for any given project or asset, for collecting, managing and disseminating each information container through a managed process. It is noted that this definition of the CDE, like that of BIM, is also somewhat vague and is open to interpretation.

It is important to recognize that ISO 19650 effectively describes a workflow for managing BIM through a manual review and approval process. This process aims to improve design coordination by defining sub-revision codes (called status codes) and introducing additional gates for checks, approvals, coordination reviews and final authorization of design deliverables. For more details on the formal CDE process, please refer to Figure 2.9.

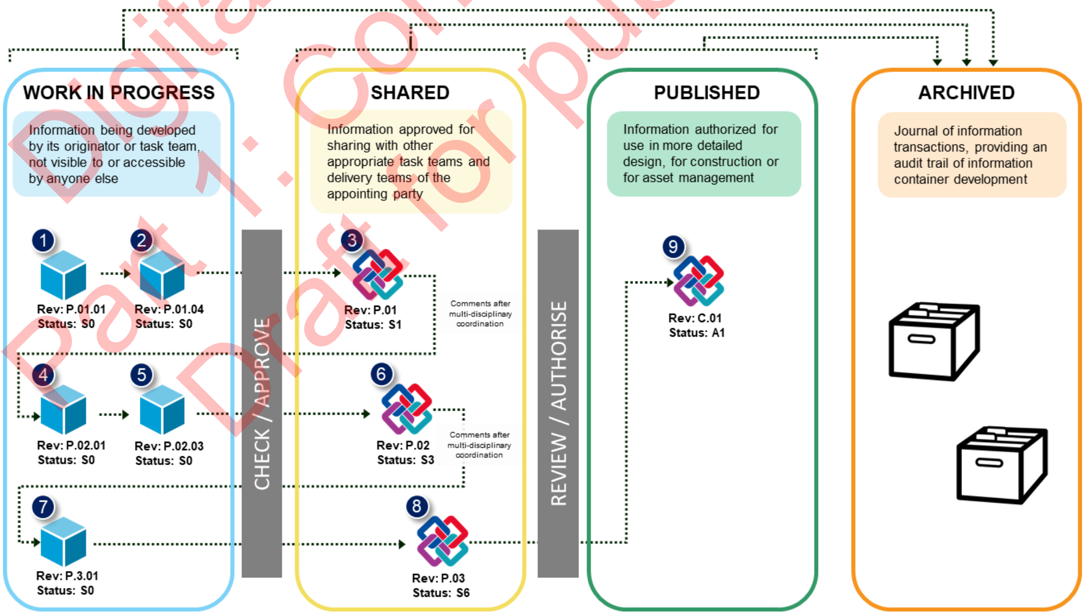


Figure 2.9: CDE process, aligned with ISO 19650 (based on diagram by BIM Corner)

This process was first developed in the UK around 2006 (by the Avanti project) and was subsequently integrated into the UK suite of BIM standards from BS1192:2007 onwards.

The CDE process has been highly beneficial for improving revision control and design coordination of geometry-based deliverables (i.e. CAD and BIM), by embedding interdisciplinary checks into standard design review and approval processes.

This helps to mitigate design clashes between disciplines, and ensures all parties are currently sharing and externally referencing the most recent versions of each other's designs.

More broadly, throughout industry there is still a general lack of clarity on the architecture, software requirements and relative ICT boundaries of the CDE process. Furthermore there is ongoing industry certainty on whether the CDE process has relevance to datasets beyond CAD BIM, that do not involve geometry.

Most importantly however, given this workflow dates back to 2006, the CDE process is inherently manual and is still centred on file-based data management. It does not provide any advice on process automation and more advanced database management for more efficient data management. Therefore this process requires a significant amount of administration to keep current and reliable – which is particularly challenging on complex, multidisciplinary infrastructure projects, with numerous suppliers, contracts and deliverables.

2.7.2 The connected digital ecosystem (CDE 2.0)

The current CDE process is now outdated, and we need to consider a more modern approach to data production and exchange, that applies more advanced data management capabilities.

The next evolution of the CDE is the Connected Digital Ecosystem (CDE 2.0). This is defined as a digital ecosystem of linked databases, that manages and exchanges datasets & metadata, using consistently structured data architecture, to ensure semantic interoperability over the asset lifecycle.

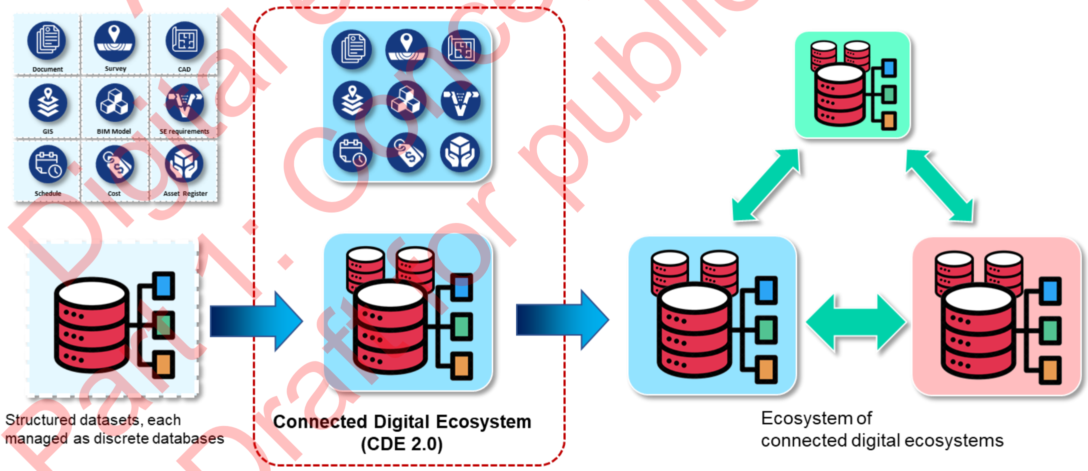


Figure 2.10: Formation of the Connected Digital Ecosystem (CDE 2.0)

Represented above to Figure 2.10, the CDE 2.0 is a scalable solution that:

(a) manages all datasets as discrete databases;

(b) builds a scalable ecosystem of databases; and

(c) enables a broader ecosystem of ecosystems.

This approach provides a structured yet flexible approach to data management, with capabilities that extend well beyond the current CDE process.

Consistent and reliable metadata management is foundational for building the CDE 2.0, in order to provide context to datasets, enabling data association and informing data-driven analytics and insights. The following section looks metadata requirements of this new approach and provides a comparison with current CDE processes.

2.7.3 Metadata requirements to support the CDE 2.0

ISO 19650 introduces the concept of metadata; however the recommended metadata fields are relatively light on detail and focus mostly on revision control to support CDE processes.

Initiatives such as the UK BIM Framework, which features the UK Annexure to ISO 19650, extend the metadata requirements to also cover document authoring and information container (i.e. file) details.

Table 2.6: Minimum metadata requirements for CDE & CDE 2.0

CDE		CDE 2.0
ISO 19650	UK BIM Framework*	Additional metadata
• Status code	• File / Container Name	• Asset Class
• Revision code	• Description	• Asset Location
	• Author	• Project Contract
	• Submittal Date	• Work Package
	• File / Container Classification	• Work Zone
		• Business/Technical Discipline
		• Lifecycle Stage/Gate
		• Author/Approver/Owner
		• Approval Status
		• etc

** from UK BIM Framework Guidance Part C Edition 1 - September 2020*

Referring above to Table 2.6 the diversity of metadata fields within CDE 2.0 extend well beyond existing ISO 19650 and UK BIM Framework requirements. These additional fields provide a range of new data management capabilities and enable infrastructure assets to be managed much more effectively than the existing CDE process. Further details on the metadata required to support the CDE 2.0 are provided in Section 3 of this Standard.

2.8 The future with structured data

2.8.1 Data, information, knowledge & wisdom

Data is crucial for making smarter, more informed business decisions, that are based on objective comparable and verifiable information. The progression from data to wisdom is often represented in a four-level pyramid, as provided in Figure 2.11.

Data is positioned as the bottom layer of this model – highlighting the importance of data for building business intelligence and enabling more informed business decisions.

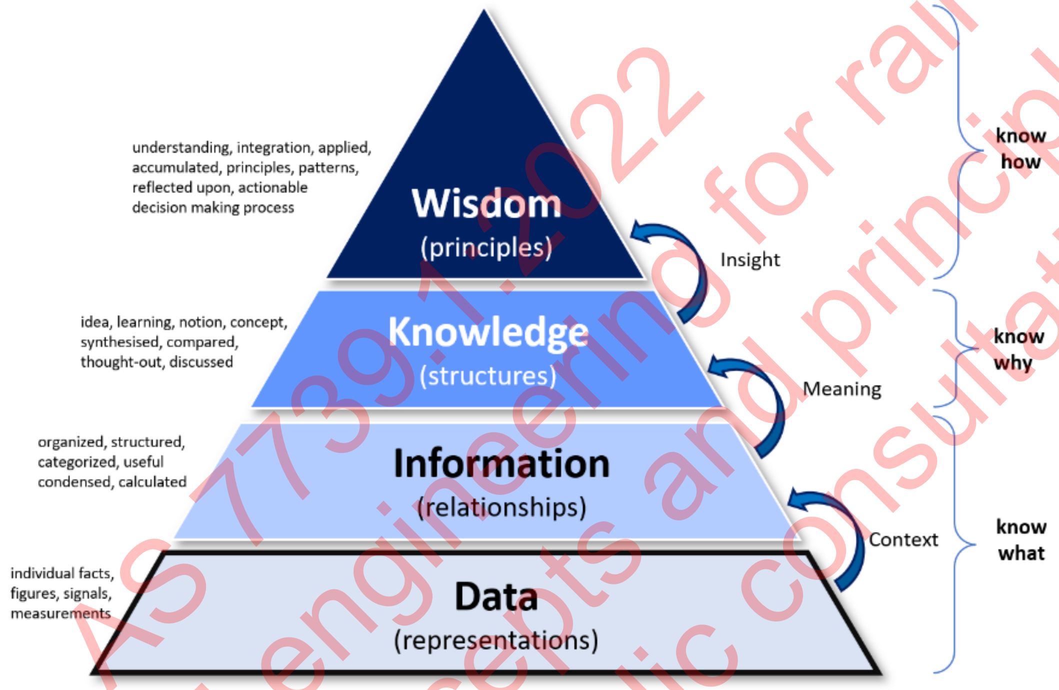


Figure 2.11. Relationship between Data, Information, Knowledge & Wisdom (DIKW)

In relation to the rail infrastructure industry, there is a need for consistently structured data, to derive meaningful analysis or insights across projects, portfolios, or infrastructure networks as a whole.

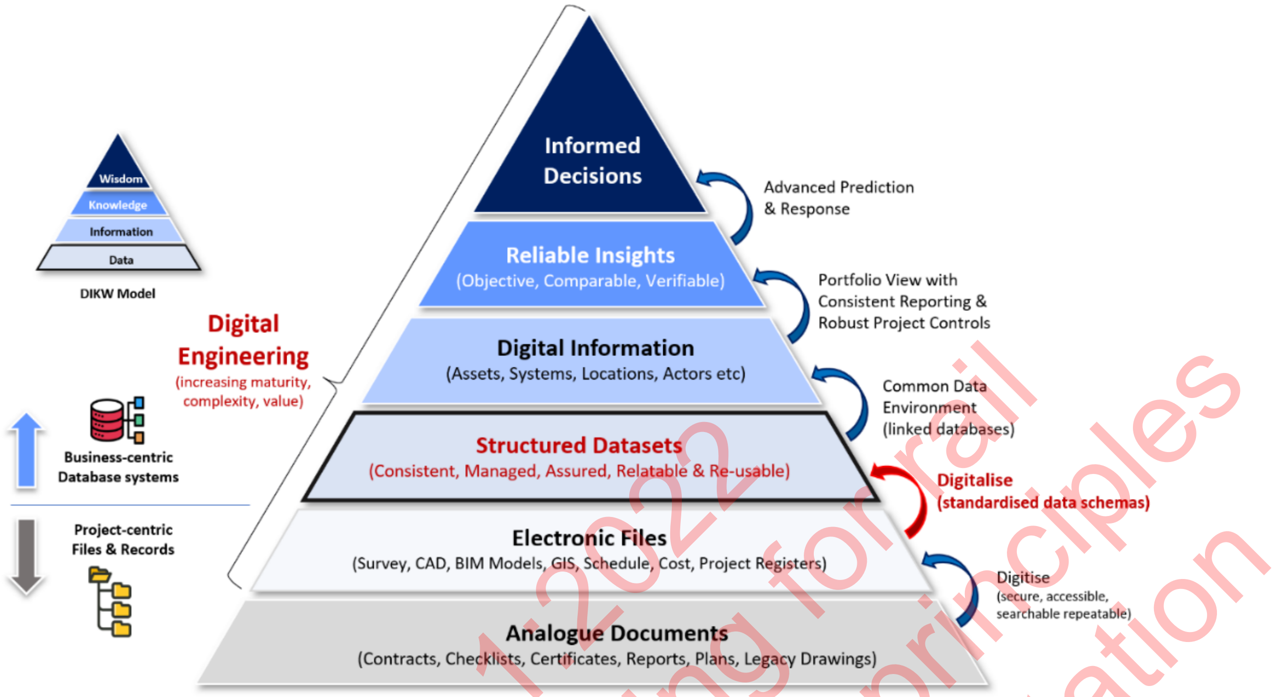


Figure 2.12: DIKW pyramid, overlaid with Digital Engineering

As represented in Figure 2.12 above, the rail infrastructure industry still manages much of its information in analogue documents e.g. contracts, reports, manual checklists, certificates etc. Where project documents have been digitized, teams typically manage electronic files in PDF form, saved as disconnected electronic files that are stored in siloed systems.

In order to build a strong foundation of structured data, digitized documents and electronic files are not enough. The critical step is to digitalize all datasets, using standardized metadata that is managed consistently in a common digital ecosystem.

Structured data is key to ensuring all project datasets are findable and re-usable over the complete asset lifecycle. This will enable the complete historic information of any asset will be accessible and supports the long-term objectives for the digital asset lifecycle and the future vision of asset owner (digital twins).

2.8.2 CDE 2.0 over the asset lifecycle

The design of the CDE 2.0 requires new capabilities that are currently emerging and maturing in the ANZ rail infrastructure sector. Represented in Figure 2.13, the CDE 2.0 presents the opportunity to completely transform the overall asset lifecycle.

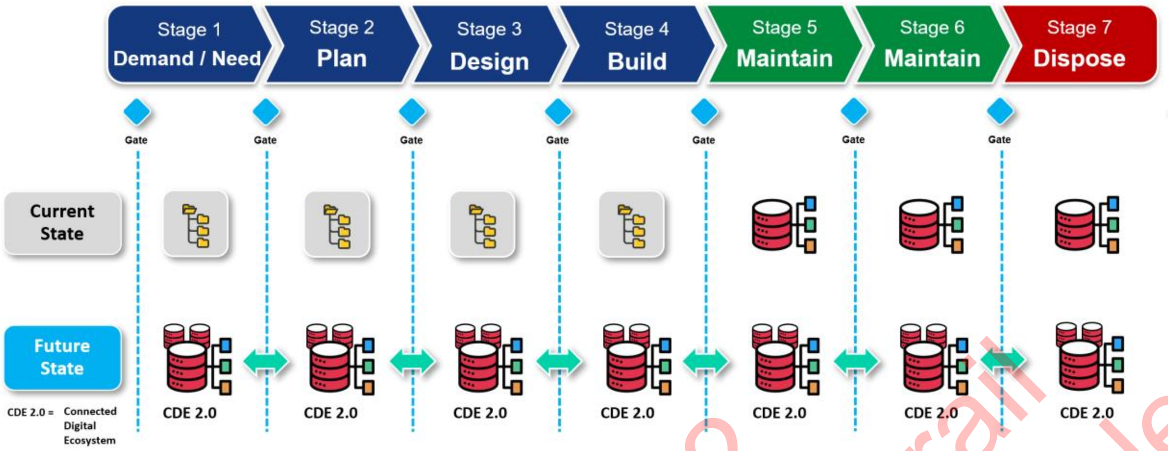


Figure 2.13: Evolution to an ecosystem of linked databases i.e. connected digital ecosystem (CDE 2.0)

When information is procured and managed as consistently structured data, project data can be built up and reliably re-used by all parties over the complete project lifecycle. At project completion, structured data enables seamless handover into operations and maintenance, enabling a step change in productivity over the full asset lifecycle. This will drive significant efficiencies by avoiding data-loss, automating manual processes and minimising the need for information to be reassured or recreated at each lifecycle stage.

2.8.3 The future of the digital asset lifecycle

This concept is now gaining attention by leading agencies globally and is commonly referred to the digital asset lifecycle (otherwise known as the digital thread or the golden thread of information). As represented in Figure 2.14, the digital thread enables full traceability of data over the complete asset lifecycle – and provides the foundation for more advanced concepts such as the digital twin. The first essential step towards building the digital asset lifecycle is the establishment of consistent DE.

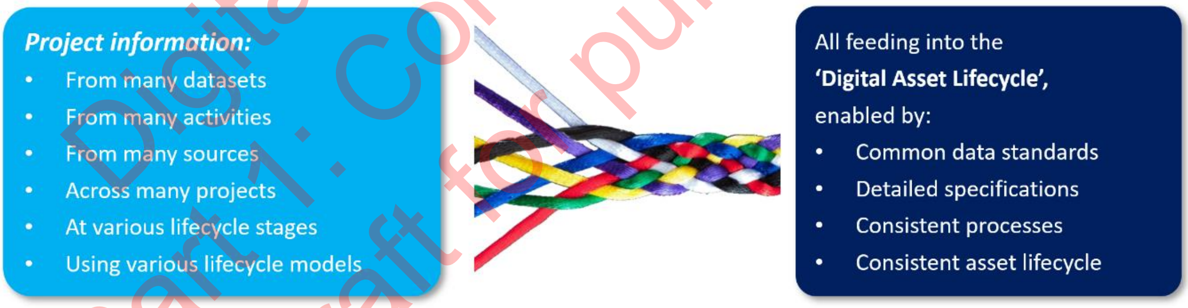


Figure 2.14: Conceptual representation of digital asset lifecycle

3 Metadata to support DE

3.1 Introduction

Metadata is defined as the data about data and is used to provide information about one or more aspects of the data. Metadata adds considerable capabilities and value, by enabling datasets to be grouped in meaningful ways and improving how specific datasets are managed, tracked and exchanged. In short, metadata is fundamental for enabling organisations to manage data as an asset.

Metadata is not a new concept to the rail infrastructure sector, as most project stakeholders will be familiar with filling in data fields such as drawing title blocks, document numbers and project codes. Metadata management in the ANZ rail industry current application of metadata demonstrates relatively low maturity however and is typically established created on projects to support single phases of the asset lifecycle only. Furthermore, many of the key metadata fields attributes used to store information are setup as with free-text fields, with little consideration for structure, or semantics and automated processing. (with machine readable entries).

Poor metadata management directly impacts the ability for data to be retrieved and / or re-used over the lifecycle. More importantly, the lack of consistent, machine-readable semantics inhibits the opportunity to relate associated datasets or support advanced process automation. In short, poor metadata management is now responsible for many of the inefficiencies associated with infrastructure delivery and asset management.

At a basic level, the digital approach considers how all project deliverables can be tagged with metadata fields, that are relevant to the whole asset lifecycle. Disconnected or project-centric metadata fields are discouraged, in favour of business-centric tagging of all relevant datasets, using semantics that are universal and interoperable. This can include a broad range of relevant metadata attributes that include, but are not limited to, asset classification and location classification, as represented in Figure 3.1. A number of other related attributes are also required, however this is covered in a later section of this document.

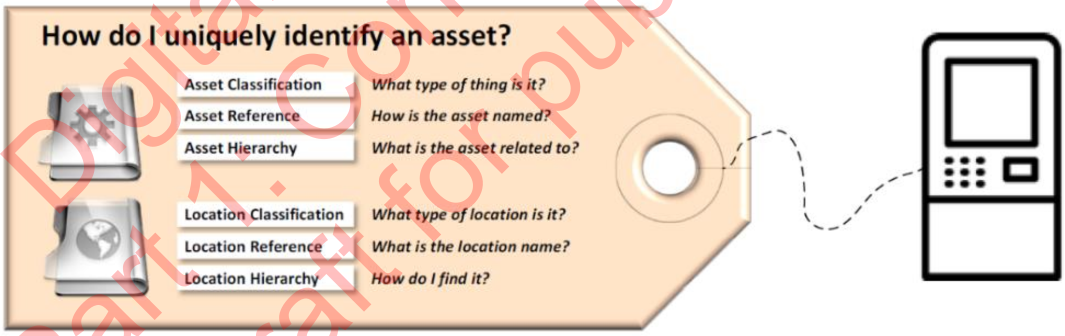


Figure 3.1 Metadata tagging with asset and location classification

Digital transformation of the ANZ rail industry requires a new approach to structured data that addresses how critical datasets, and their metadata are managed and exchanged over the infrastructure asset lifecycle. New metadata standards and specifications, supported by robust data schemas, will be essential for classifying and tagging all relevant datasets.

Once this is standardized, all parties working on a project will have the ability to procure, manage and exchange datasets consistently and securely, through a network of connected digital ecosystems over the complete asset lifecycle. This digital approach will transform how all deliverables are managed, transitioning from project-centric electronic files into business-centric structured data.

DE requires a structured approach to data management that establishes the digital ecosystem of linked databases i.e. CDE 2.0. A common data language is therefore required to enable consistent data exchange between parties, activities, and information management systems.

The common language, or semantics, should also be logical, machine readable and interoperable, to enable data federation, process automation, portfolio insights and more informed decision making. To achieve these objectives and more, the digital ecosystem should be established through common data language that supports semantic interoperability.

3.2 Key concepts for enabling semantic interoperability

3.2.1 General

Referring to Table 3.1, there are a series of terms and concepts that have emerged from the ICT sector, that will be explained in this section of the document – starting with taxonomy, which is otherwise known as classification.

Table 3.1: Key terms relating to machine readable data

Term	Definition	Meaning
Semantics	The systematic organization of data using consistent conventions, to reliably transfer information (e.g. context, meaning and relationships) about objects between parties	Common Language
Taxonomy	The process of arranging objects into meaningful groups by class	Classification; for grouping "type-of" relationships
Ontology	The process of defining relationships between objects, systems and concepts	Composition or Modelling; for assigning "part-of" relationships
Semantic Interoperability	The ability for computer systems to unambiguously exchange and federate data with universal meaning	Machine Readable Data

3.2.2 Introduction to taxonomy

Taxonomy can be considered as the first building block in an information or data architecture. It provides the first sorting of information content in an organization, by grouping similar objects by their type. This first step can dramatically improve the quality of information within an organization and can help move it from a state of chaos to a more ordered state.

Referring to Figure 3.2 taxonomy is a broad term that can be understood as a:

(a) sematic representation;

(b) classification scheme; and a

(c) knowledge map.

Taxonomies identify hierarchical relationships within a category, however in isolation these have their limitations. Taxonomies cannot represent relationships across different domains; they can only define categories within single domains.

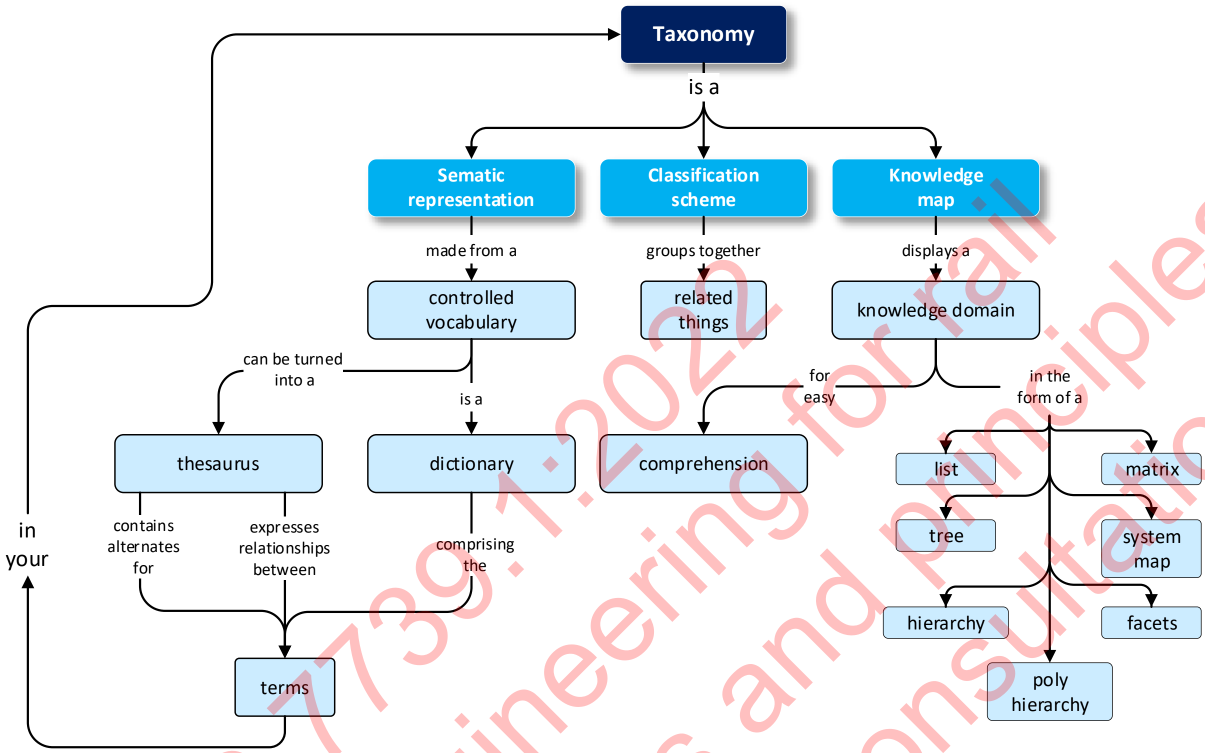


Figure 3.2: What is taxonomy?

3.2.3 Introduction to classification

Classification is the process of arranging things into meaningful groups by properties or class. Classification systems assign type-o relationships to objects based on their properties.

For example, referring to Figure 3.3, the objects have been classified by their size, however other properties such as shape and colour could also be applied.

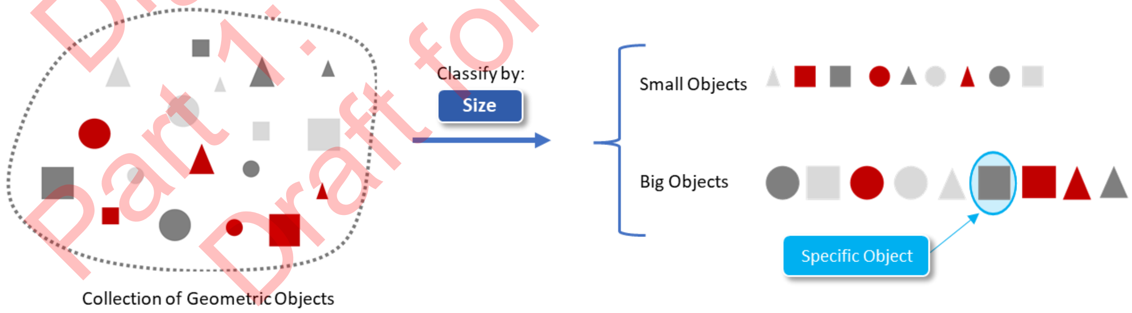


Figure 3.3: Collection of objects classified by size

(Diagram source: [Les systèmes de classification et le BIM (cstc.be, 2019)](#))

It is noted that a single level of classification in this example is too broad to identify specific objects, and further levels of classification would be required for more specific purposes.

3.2.4 Introduction to ontology

Ontologies build on the concept of taxonomy, by providing the connections or relationships between entities. Ontologies can also be described in the form of data models, as they define how entities for part-of a system, or a broader system of systems. See Figure 3.4 for an example ontology from the IFC open BIM data model.

Ontologies provide stronger semantics that taxonomies, by providing richer, more detailed information. Ontologies can reflect both a very detailed description of about specific entities, as well as broad views of an overall enterprise or portfolio of entities.

This form of modelling is a critical process for building consistent data architecture within an organisation or for reliable data exchange between multiple organizations within an overall sector.

It is important to note that merely creating a set of taxonomies does not mean an ontology has been created. The interrelationships among the entities in a taxonomy are the essence of an ontology.

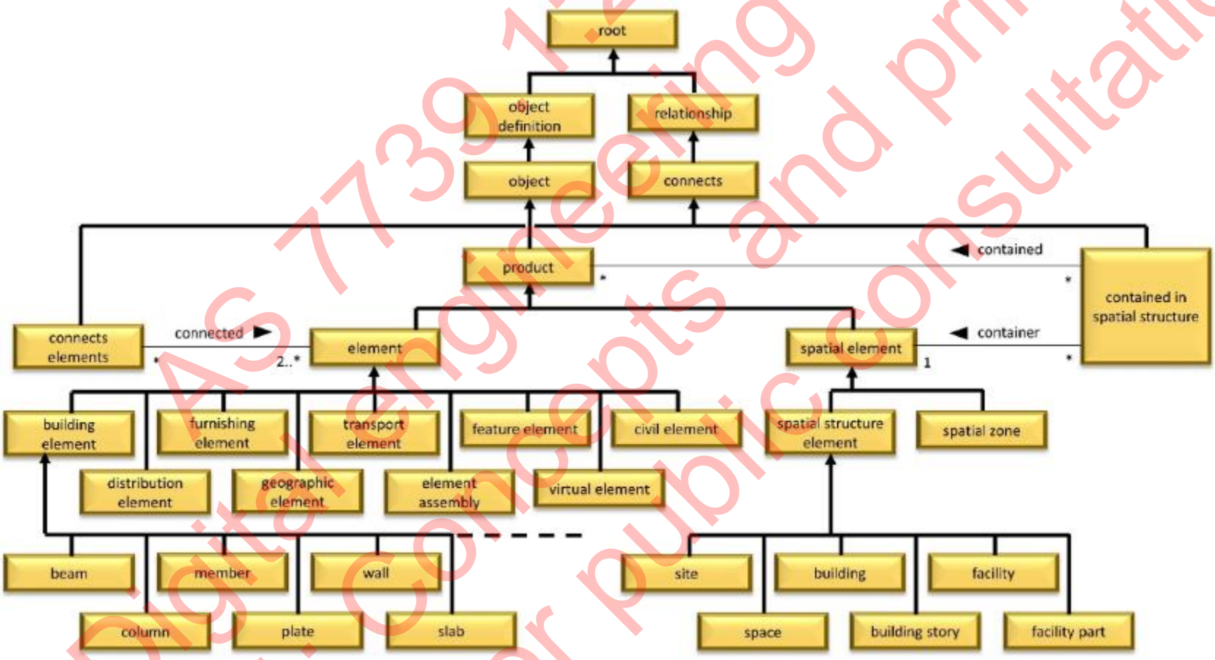


Figure 3.4: Example ontology from the IFC openBIM data model

(source: [A Survey of Industry Data Models and Reference Data Libraries (cdbb, Nov 2020)](#))

3.2.5 Introduction to semantic interoperability

Semantic interoperability can be defined as the ability for computer systems to unambiguously exchange and federate data with universal meaning. When working in an environment with semantic interoperability, data arrives pre-packaged with self-described context, and the consumer of that information can derive meaning through a universally agreed language (i.e. semantics).

Semantic interoperability allows organizations to treat data as a living asset, that can be used and reused, combined, exchanged and understood by a variety of systems. Semantic data repositories support analytical capabilities, ease the integration of diverse sources, and ultimately provide the foundation for digital ecosystems.

The front-loaded effort in creating or mapping to a semantic ontology might seem burdensome, however once established, semantic interoperability offers significant benefits as provided in Table 3.2.

Table 3.2: Benefits of data management with semantic interoperability

Capability	Benefit
Data exchange	Data is this form can be effectively read and interpreted by machine, supporting automated processes such as machine-to-machine communication with limited or no human interaction.
Data federation	Semantic data integration provides a seamless and autonomous way of combining data sources and presenting them to applications as if they were pulled from the same source.
Data insights	Data in this form enables organizations to determine relationships, uncover patterns and gain insights through more advanced data analytics

Semantic interoperability is essential for effective data management and forms a core requirement for successful DE implementation. It is therefore necessary to understand the requirements for effective taxonomy which, in the context of DE, relies on classification.

3.3 Types of classification

3.3.1 Introduction

Classification systems offer a range of organization benefits such as the following:

(a) Consistently structured organizational data.

(b) Standardized terminology throughout the organization.

(c) Extracting meaningful information from unstructured data.

(d) Intelligent search capabilities (of all relevant data).

(e) Re- use of data for other analytics/dashboards.

(f) Machine Readable data – in the form of consistent structured databases.

There are many types of classification however, in regard to the built environment, most classification systems fall under three main categories:

(g) Hierarchical classification.

(h) Faceted classification.

(i) Combined hierarchical and faceted classification.

These forms of classification are explained further.

3.3.2 Hierarchical Classification

Hierarchical classification (otherwise known as fixed or enumerative classification) defines top-down grouping, subdividing classes systematically from the most general down to highly specific. Referring to Figure 3.5, this example demonstrates the how a three-level classification system groups a random collection of geometric objects down to specific objects.

Key strengths of a hierarchical classification are its absolute consistency and predictability, making them well suited for highly-structured physical systems.

That said, this form of classification is highly rigid, with only one kind of relationship permitted between classification groupings (i.e. levels). Furthermore, hierarchical classification does not perform well with complexity or a changing environment; where perhaps a more flexible approach could be required.

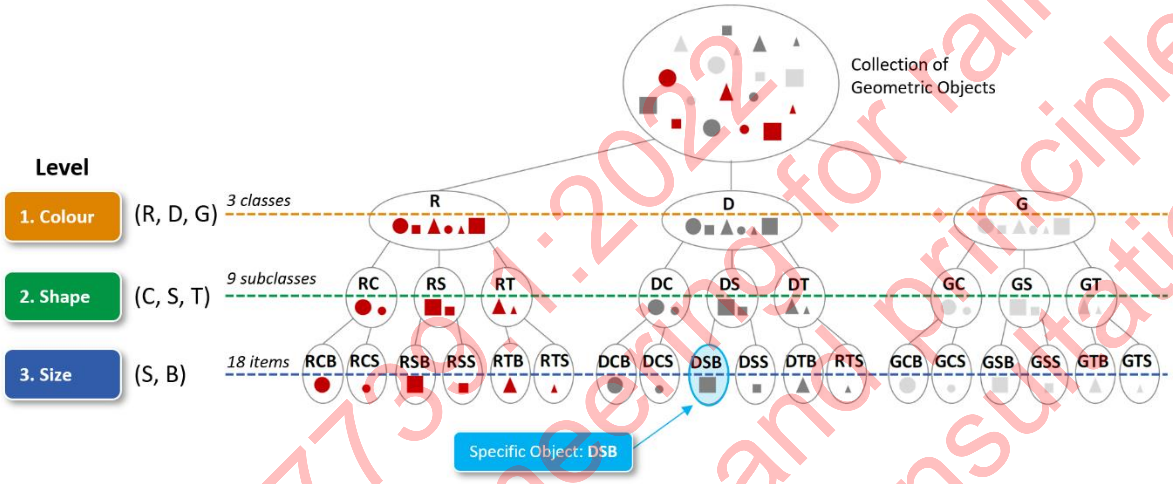


Figure 3.5: Hierarchical classification system

3.3.3 Faceted classification

Faceted classification defines systematic grouping without any form of hierarchy. This lack of defined structure enables users to apply the classification in multiple ways rather than in a single, predetermined order.

Faceted classifications are inherently flexible, allowing individual tables to be adjusted at any time, without impacts to other facets and disruption over the system. Therefore, they are considered difficult to break, and are more suitable in organizations with a complex or changing environment. The lack of clear structure however can also make these challenging to use, as the increased complexity make require more time to interpret and apply.

Referring to Figure 3.6, this example demonstrates the how a faceted system is applied to identify a specific object, by filtering each of the 3 classification tables.

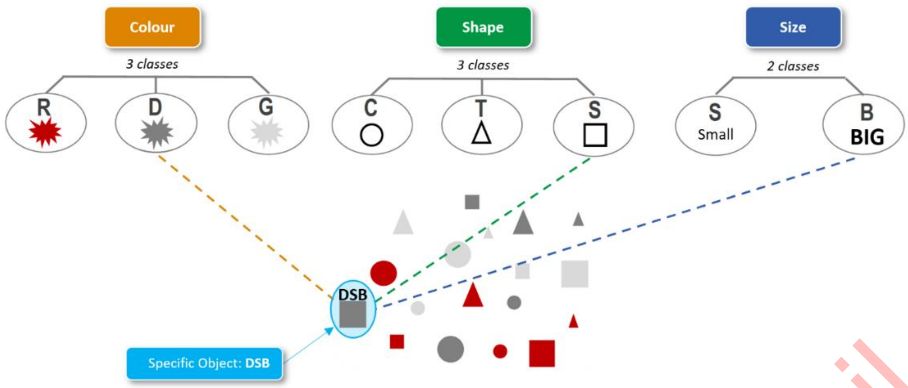


Figure 3.6: Faceted classification system

3.3.4 Combined hierarchical and faceted classification

The third type of classification combines hierarchical and faceted classification. This effectively brings together the best of both worlds by enabling structured hierarchies where appropriate, while leaving other groupings open and flexible.

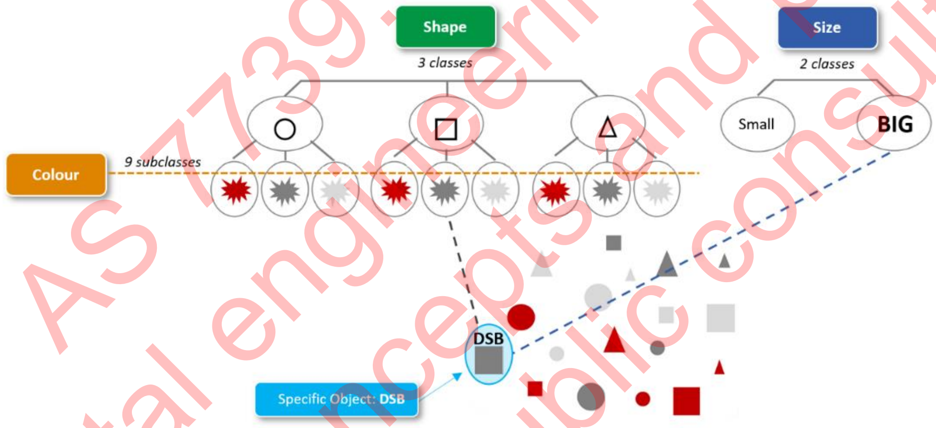


Figure 3.7: Combination of hierarchical and faceted classification systems

Referring above to Figure 3.7, this diagram represents the basic structure of a combined classification system. It is noted numerous existing classification systems have adopted this approach e.g. Uniclass 2015 has 12 facets (or tables), that each provide up to 4 levels of classification (from Level 1 Groups down to Level 4 Objects).

3.4 Characteristics of effective classification

Classification systems define many of the semantics necessary to support DE and are foundational for building the CDE 2.0. When assessing the suitability of a classification system, there are several characteristics that should be considered (Table 3:3).

Table 3.3 lists some of the key characteristics for effective classification.

Table 3.3: Characteristics of effective classification

No.	Characteristics	Details
1	Semantic	Provides logical structure, that is machine readable to support accessibility, automation and re-use
2	Consistent and predicable	Applies logical and familiar structures to enable navigation and usability
3	Complete	Represents all classes and objects relevant to users
4	Flexible	Enables a wide range of users to apply uniformly in a broad range of use-cases
5	Intuitive	Relatively simple to understand and apply
6	Supported	Proactively managed and administered, with frequent and regular improvements
7	Portable	Enables convenient application and sharing across multiple platforms
8	Extensible	Ability to expand with new concepts and object classes
9	Parsimonious	No redundancy or repetition, and offers no more and no less than what is required
10	Durable	Robust system, that does not require radical change or reorganization

The challenge of developing an effective classification for the built environment has been considered globally through the publication of the international standard ISO 12006.2:2015. This Standard is explained in detail in the following section.

3.5 Introduction to ISO 12006.2-2015 – Framework for classification

3.5.1 Introduction

ISO 12006.2 is an international standard that provides a framework for developing classification systems for the built environment. First published in 2001, the second (and current) release was published in 2015 to cater for advances in BIM and emerging technologies. As such, this Standard is referenced numerous times throughout the ISO 19650 set of standards.

It is important to note that ISO 12006.2 does not provide an actual classification system. Instead it defines best practice, by providing the core elements necessary for developing classification systems and tables. The standard is intended for use by governments and organizations seeking to develop their own classification systems, with flexibility to suit specific user needs. Any resulting classification systems and tables developed using this Standard will be relatively harmonized, through a consistent approach to classification.

3.5.2 Classification framework

ISO 12006.2 defines a conceptual framework or model that groups specific forms of classification where construction processes use construction resources to achieve construction Results. See Figure 3.9 for the full diagram of this model.

Notably, this Standard uses the term construction specifically to describe physical assets that comprise the built environment. Referring to Figure 3.8 the standard covers all processes and activities over the complete asset lifecycle, from planning through to operations and maintenance.

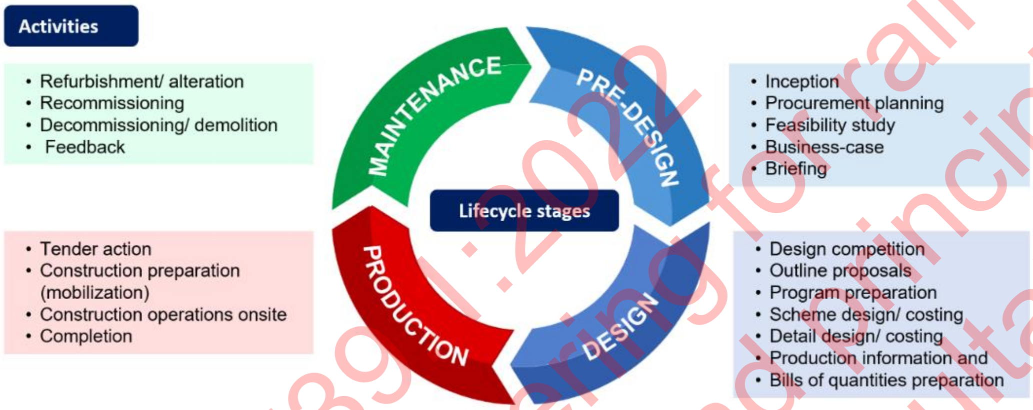


Figure 3.8: ISO12006.2 construction process examples across lifecycle stages

ISO 12006.2 defines a set of recommended classification tables for a range of information object classes according to particular views, e.g. by form or function, supported by definitions.

Referring to Figure 3.9, the standard indicates how the object classifications in each table are related, as a series of systems and sub-systems, that are relevant to most building or infrastructure projects.

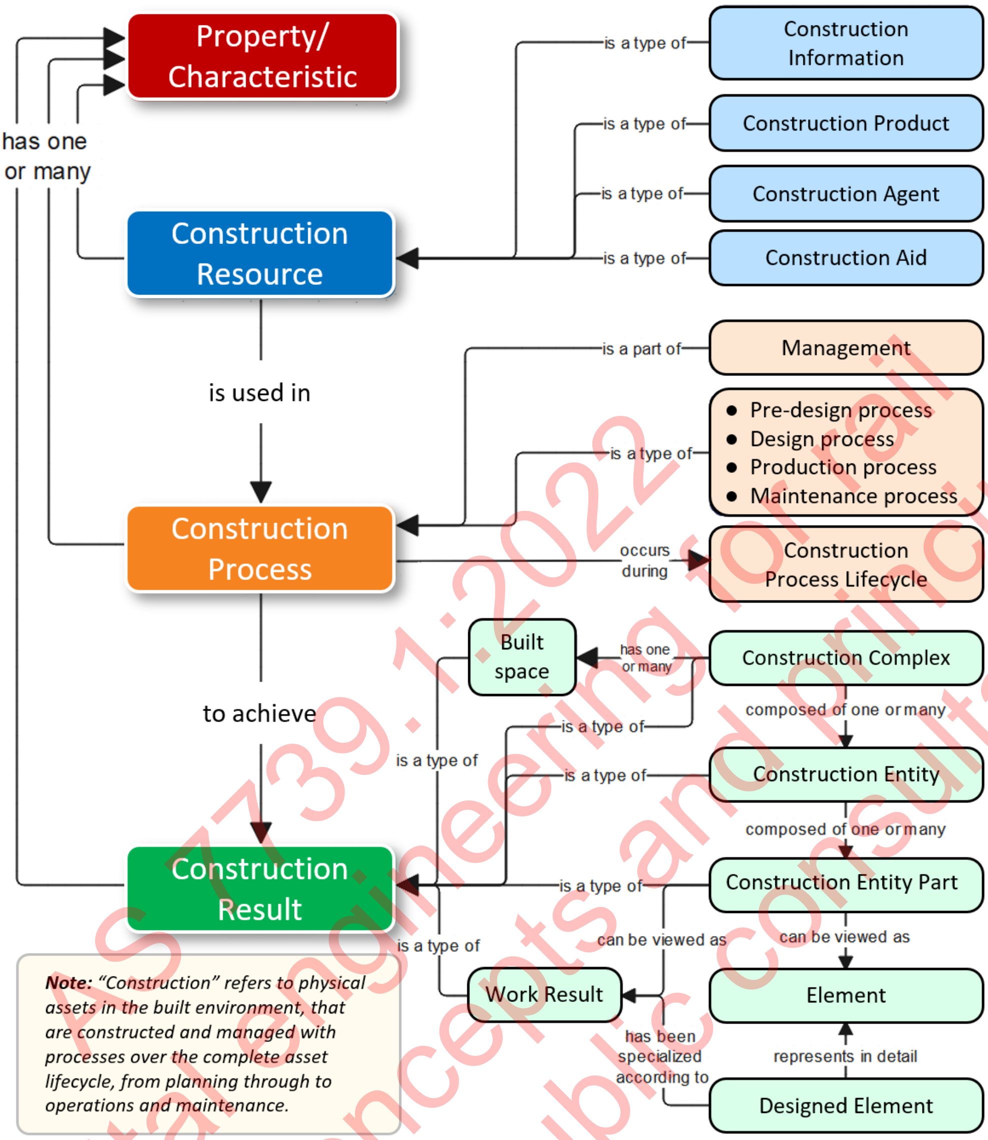


Figure 3.9: Overview of the ISO 12006.2 ontology

This model is highly effective for breaking down any type of project into a series of components and sub-components, using a systematic process. That said, terms used in this Standard can seem somewhat abstract and could be unfamiliar to parties seeking to understand and apply this approach.

Referring to Table 3.4, a selection of key terms and definitions are listed, with effective translations and examples to help explain the core concepts of this Standard.

The next step is to consider an appropriate asset classification standard, that aligns with this international standard and provides the necessary semantic data management capabilities to support DE.

Table 3.4: Selection of terms and definitions from ISO 12006.2

Term	ISO Definition	Meaning	Examples
Construction Resource	Construction object used in a construction process to achieve a construction result	Roles, tools, built assets and information	**Roles:** Civil engineers, project managers etc **Tools:** Excavators, formwork, computers etc **Built assets:** Structures, services, fixtures & fittings etc **Information:** Specifications, schedules, drawings etc
Construction Product	Product intended to be used as a construction resource	Individual built environment assets, broken down to the maintainable objects	**Function:** civil, structural, fixtures etc., or **Material:** timber, metal, glass etc.
Construction Process	Process which uses construction resources to achieve construction results	Management processes and activities over the complete asset lifecycle	Processes and activities for: Project management Asset management
Construction Process Lifecycle	Sequence of stages from the start to the end of the construction process	Asset lifecycle stages, or breakdown of more specific activities during stages	**Lifecycle stage:** pre-design, design, production, maintenance **Activity:** planning, procurement, mobilization, refurbishment etc.
Construction Result	Construction object which is formed or changed in state as the result of one or more construction processes using one or more construction resources	Built environment elements, grouped by form or function or user activity	Infrastructure and buildings
Construction Complex	Aggregate of one or more construction entities intended to serve at least one function or user activity	Highest level grouping of built environment facilities or infrastructure networks	Complexes: Rail network Hospital Shopping centre
Construction Entity	Independent unit of the built environment with a characteristic form and spatial structure, intended to serve at least one function or user activity	Breakdown of complexes, with sub-grouping by form, function, or user activity	Entities: Rail line or Train station Hospital ward Food court etc.
Built space	Limited three-dimensional space defined by built or natural environment or both, intended for user activity or equipment	Three dimensional zones, grouped by form, function, user activity or any combination such as human activity, storage, or technical systems	Spaces: Corridor section Station platform Operating theatre Shop etc.

Construction Element	Constituent of a construction entity with a characteristic function, form, or position	Breakdown of built environment into functional systems, that are assembled by grouped products	Structural system, electrical system, ventilation system, transportation system etc

3.6 Comparison of current classification standards against ISO 12006.2

In recent years, there have been several studies into the characteristics and capabilities of major asset classification standards from around the world, to determine how they compare against with ISO 12006.2. These studies have been undertaken by several organizations including Transport for NSW, NATSPEC and CSTC (Belgium) and buildingSMART France.

The outcomes of these studies have repeatedly concluded that Uniclass 2015 as the preferred standard, that most successfully aligns with ISO 12006.2 (as demonstrated in Table 3.5) and possesses many of the characteristics presented earlier.

Table 3.5: Alignment of Uniclass 2015 with ISO 12006.2

	ISO 12006-2:2015			Uniclass 2015 (UK)	
	Table Reference and class		Classified by	Table Reference	
Construction Resource	A.2	Construction Information	Content	FI	Forms of information
	A.3	Construction Product	Function or form or material*	Pr	Products
	A.4	Construction Agent	Discipline or role*	Ro	Roles
	A.5	Construction Aid	Function or form or material*	TE	Tools & Equipment
Construction Process	A.6	Management	Management activity	PM	Project Management
	A.7	Construction Process	Construction activity or construction process lifecycle stage*	-	-
Construction Result	A.8	Construction Complex	Form or function or user activity*	Co	Complexes
	A.9	Construction Entity	Form or function or user activity*	En	Entities
	A.10	Built Space	Form or function or user activity*	SL	Spaces/Locations
				-	-
	A.11	Construction Element	Form or function or user activity*	EF	Elements/Functions
				Ss	Systems
	A.12	Work Result	Work activity and resources used	-	-
	A.13	Construction Property	Property type	-	-
	-	-	-	Ac	Activities
	-	-	-	Zz	CAD
	-	-	-	-	-

3.7 Uniclass 2015 classification standard

3.7.1 Introduction

Uniclass 2015 is a unified classification system that was developed to support all sectors of the UK construction industry. It contains consistent tables classifying items of all scales, from entire systems such as a railway to individual product items such as anchor plates, flue liners or LED lamps.

Table 3.6: Uniclass 2015 tables

Coding	Uniclass 2015	No. Objects (Jul 2021)	Definition	Transport Examples
Co	Complexes	389	Top level asset containers that describe the overall collection of assets.	Rail networks, road network, interchanges, facilities, ports etc
En	Entities	518	Independent units of the built environment with a characteristic form and spatial structure, intended to serve at least one function or user activity.	Sections of linear networks (e.g. rail lines, roads etc) and discrete structures (e.g. buildings, stations, bridges, tunnels etc)
SL	Spaces / Locations	1038	Spaces or locations are designated areas where an activity or function takes place. Also used to divide the asset into suitable sections.	Road Lanes, lines, stops, concourses.
EF	Elements / Functions	107	**Elements:** Main components of a building (floors, walls and roofs) or of a structure, (e.g. bridge foundations, piers and deck) **Functions:** Services provided/managed by the asset	Structural elements and high-level functions
Ss	Systems	2383	Systems are collected to describe an element or a function. Systems are collections of products that work together to perform a specific function	HVAC, security, communications, ticketing, FF&E, fire, control and constructions (e.g. pavement, walls, floors, ceilings, roofs and structures).
Pr	Products	7824	Products are the individual items sourced and supplied to build up a System.	Conductor rails, Rail track tie bars, Hot-rolled asphalt (HRA) surface courses and slurries
Ac	Activities	925	Things that are happening or being done.	
FI	Form of information	95	Information of interest in a construction process.	Mapped for use in project document management metadata.

PM	Project Management	735	Control activity on as construction process by one or more construction agents.	
Ro	Roles	232	Roles and actors responsible for carrying out construction process.	
TE	Tools and Equipment	827	Construction resource intended to assist in carrying out a construction process.	
Zz	CAD	129	CAD layer naming.	Recommend client CAD standard

Uniclass 2015 is free to access and use and is actively maintained and updated by NBS (UK), in consultation with industry partners around the globe. The structure of Uniclass 2015 is dynamic and supports further additions and revisions as new technologies or uses are introduced. Uniclass 2015 is constantly growing and, as of January 2022, it currently defines over 15,000 object classes.

Uniclass 2015 is comprised of 12 tables overall, however in reality there are just six key tables that are generally necessary to support DE over the general infrastructure asset lifecycle, as listed in Table 3.7.

Table 3.7: Uniclass 2015 - six key tables for DE

Location Classification		Asset Classification	
Co	Complexes	EF	Elements / Functions
En	Entities	Ss	Systems
SL	Spaces / Locations	Pr	Products

The hierarchical model (or ontology) of Uniclass 2015 provides a structured breakdown of physical object classes from complexes down to products, based on congruence between classes where possible.

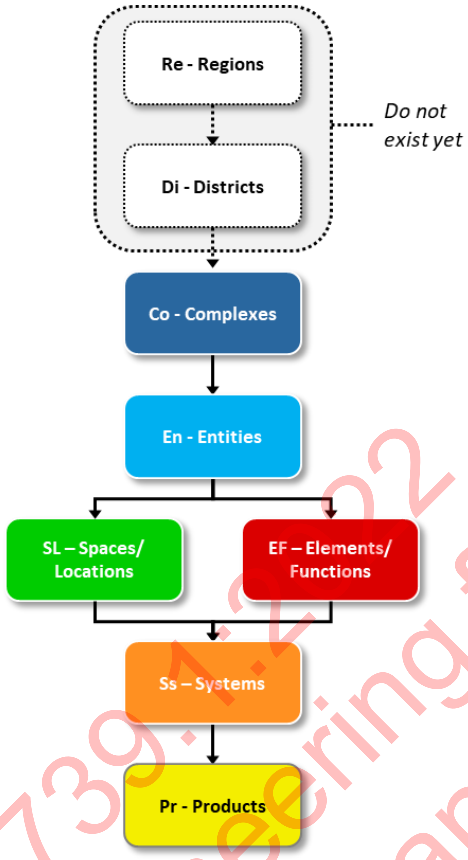


Figure 3.10: Uniclass 2015 ontology

Referring above to Figure 3.10 , Uniclass 2015 classifies physical objects up to complexes, which is aligned with the highest level of ISO 12006.2. Higher levels of classification such as regions and districts do not yet exist in Uniclass 2015, however these could be introduced future to support broader objectives such as smart precincts/ cities, and the merge of BIM and geographic information systems (GIS).

In 2015, the structure of Uniclass was carefully revised to closely align with ISO 12006.2, as highlighted in Figure 3.11. This added the benefit of making it more suitable for use with modern construction industry practices, and to make it compatible with BIM processes.

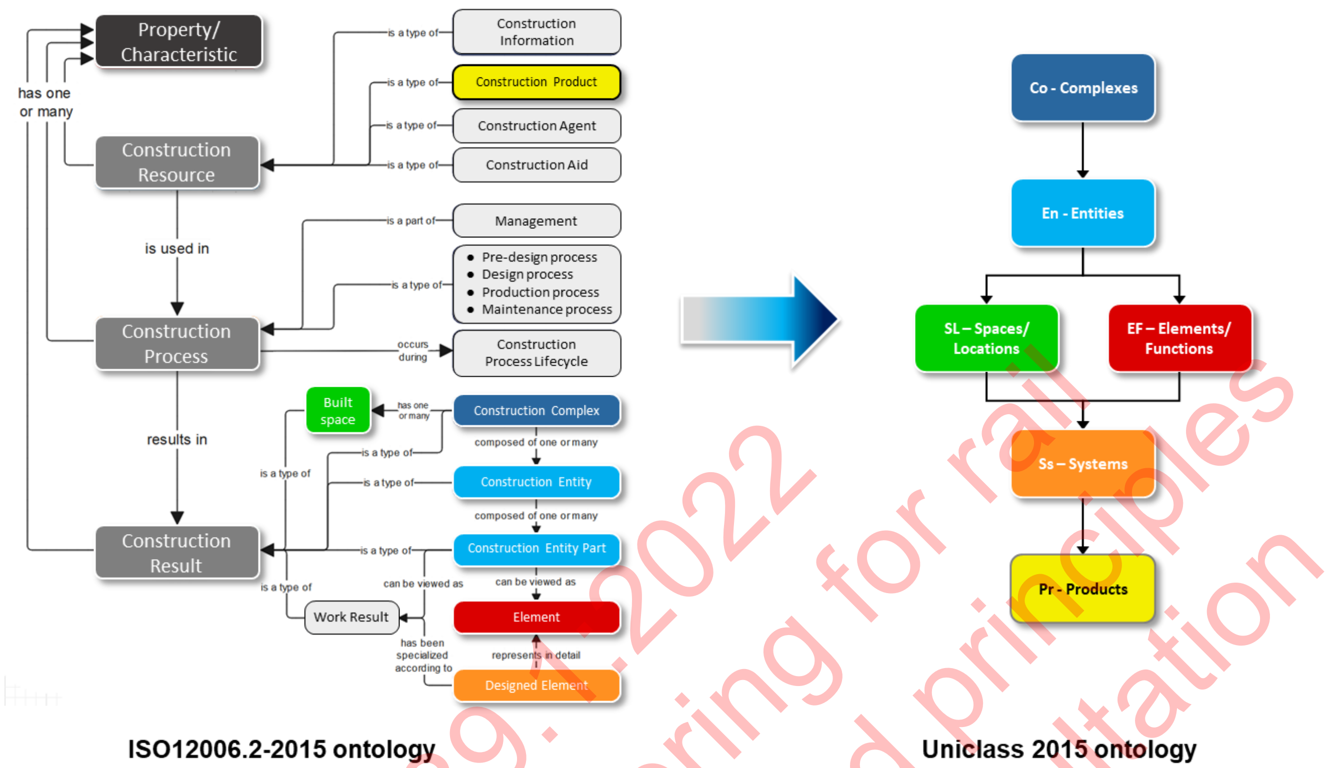


Figure 3.11: Uniclass 2015 alignment with ISO 12006.2

Uniclass 2015 is therefore particularly suited for use in an international context, as it can easily be mapped to other similarly compliant schemes around the world. Key capabilities of Uniclass 2015 include:

(a) a unified classification system for the construction industry – that brings together buildings, landscape and infrastructure under one unified scheme;

(b) a hierarchical suite of tables that supported classification from a university campus or road network to a floor tile or kerb unit;

(c) a numbering system flexible enough to accommodate future classification requirements;

(d) a system compliant with ISO 12006 that is mapped to numerous other digital initiatives and supports mapping to other classification systems in the future;

(e) a classification system that is continuously maintained and updated by NBS;

(f) Uniclass 2015 provides a means of structuring project information essential for the adoption of BIM. Information about a project can be generated, used and retrieved throughout the built asset life cycle.

3.8 Benefits of Uniclass 2015

Uniclass 2015 provides a superior form of classification and offers numerous benefits as listed in Table 3.8.

Table 3.8: Benefits of Uniclass 2015

Benefit	Details
Industry adoption	Access to skilled individuals who are familiar with the Uniclass 2015 classification system across industries and jurisdictions
Supply chain integration	Ability to author and communicate design and construction requirements with industry suppliers in a consistent and accepted manner.
Standard library of objects	Ability to leverage component models that are already attributed with classification data.
Standard development and integration	Automatic access to the improvement of the standard over time, including efforts to align other industry standards (e.g. IFC, RailML, ICMS, NRM, GS1, GML etc.)
Quality control	Improved quality control, with ability to check content for consistency and completeness.
Software compatibility	Uniclass 2015 is a DE-compatible classification standard which is readily supported by major software vendors. The ability to leverage software tools that are compatible with the standard improves the ease of adopting the standard.
Actively managed	Uniclass 2015 is proactively managed by NBS, that updates tables on a regular quarterly cycle and responds to requests for new asset classifications within 2 business days.

3.9 Structure of Uniclass 2015 coding

Each of the Uniclass 2015 tables follows a common internal organization of classifications and features a 4-level classification hierarchy, with each level providing a greater level of specialization within a given classification group, as represented in Table 3.9.

Table 3.9: Structure of Uniclass 2015 coding

Level	Detail	Code format
L1	Group	Aa_00
L2	Sub-group	Aa_00_00
L3	Section	Aa_00_00_00
L4	Object	Aa_00_00_00_00

Each individual classification is assigned a code which follows a prescribed format, where the first two alphabetic characters identify the Uniclass 2015 table and the following set of numbers (separated by "_") not only serve to allocate a unique number to the classification but also communicates the level within the specialization hierarchy.

By defining a consistent coding structure for asset and location breakdown Uniclass 2015 enables users to drilldown from high-level groups down to specific objects. An example from the Uniclass system table, demonstrating a system breakdown from a high level to the specific advertising display system, is shown in Figure 3.12

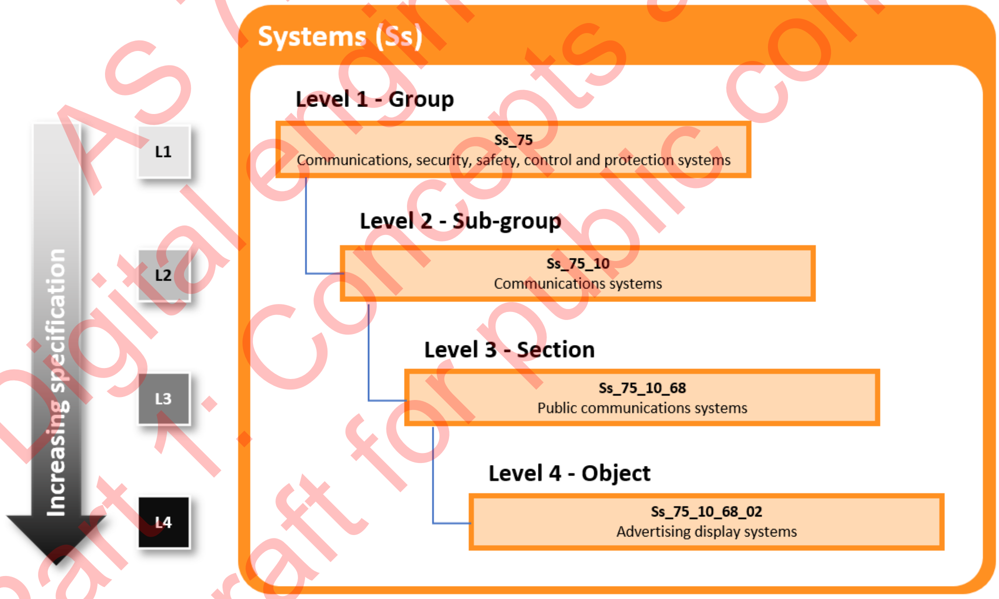


Figure 3.12: Example of the four-level coding structure, taken from Ss-Systems table

This feature of Uniclass 2015 is highly effective for managing consistent classification and data traceability over the asset lifecycle. It is particularly beneficial as the project progresses from planning through to construction, from high-level concept design (when preferred solutions are known only at a high-level), through to as-built information (when all components known down to the specific object type).

Referring to Figure 3.13, the minimum level of classification increases progressively over the course of the project. This can vary for different project deliverables to ensure only essential information is requested and is not overly complicating an already fairly extensive process.

Design Development →

			3. Concept Design	4.1 System Breakdown Review	4.2 Preliminary Design Review	4.3 Detailed Design Review	4.4 Final Design Review	5.1 Final Specification Review	5.2 As-Built Review
Location	Co	Complexes	L1	L2	L2	L3	→	→	→
Location	En	Entities	L1	L2	L2	L3	→	→	→
Location	SL	Spaces / Locations	L1	L2	L2	L3	→	→	→
Asset	EF	Elements / Functions	L1	L2	→	→	→	→	→
Asset	Ss	Systems	L1	L2	L3	L4	→	→	→
Asset	Pr	Products	-	-	L2	L3	→	→	→

Figure 3.13: Design development with minimum level of Uniclass 2015 classification

3.10 Uniclass 2015 – revised ontology to support DE

3.10.1 General

A key strength of Uniclass 2015 over comparable classification systems is its open structure and inherent flexibility, which allows its tables to be adapted and applied in a variety of applications. This makes it highly suitable for the infrastructure sector, which contains a broad spectrum of use cases over the complete asset lifecycle. This also allows Uniclass 2015 to be adapted and applied to numerous types of datasets, that are stored in a wide range of formats and software platforms.

DE capitalizes on this flexibility, by reshaping the ontology of Uniclass 2015 (presented earlier), into a less hierarchical, more open structure. Referring to Figure 3.14, the revised ontology of Uniclass 2015 is broken into two separate structures:

(a) Location Classification – including Complexes, Entities and Spaces/Locations.

(b) Asset Classification – including Elements/Functions, Systems and Products.

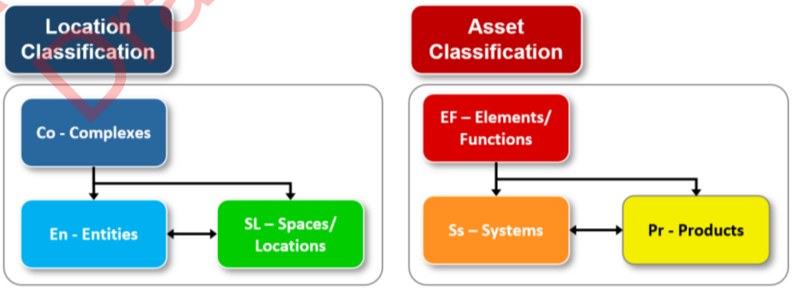


Figure 3.14: Uniclass 2015 – separated ontology

The way assets are organized into asset hierarchies is independent of their location and the location hierarchy. Both views are necessary, valid and co-exist at the same time. Each of these two structures are independent, providing discrete and meaningful ways to model the composition of physical infrastructure, that avoid any crossover between the two approaches.

The individual ontologies of the two structures utilize the flexible characteristics of Uniclass 2015, by adopting a relatively open approach to the system decomposition. This enables Uniclass 2015 to be truly universal in application and supports modelling for the broadest possible range of modelling combinations.

Referring to Figure 3.15 and Figure 3.16, the table hierarchies are flexible to suit activities over the complete asset lifecycle. For example:

(a) high-level option assessment of a new rail line;

(b) installation of a simple, passenger bench seat on train station platform;

(c) detailed inspection of complex maintainable assets in a high voltage substation.

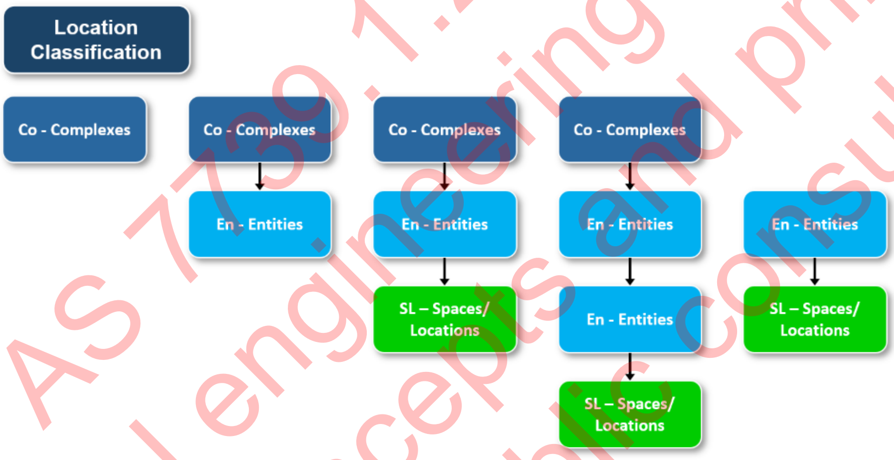


Figure 3.15: Uniclass 2015 location classification – flexible hierarchies

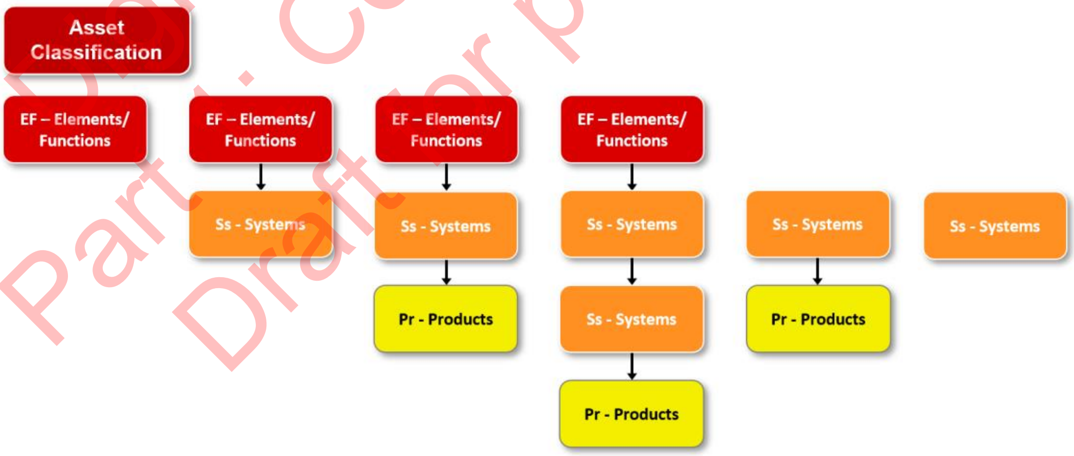


Figure 3.16: Uniclass 2015 asset classification – flexible hierarchies

Both forms of classification are required to model physical assets and are associated together using a standardized ontology. Uniclass 2015 provides a relatively simple and flexible ontology for associating the two forms of classification together in a single model, as represented in Figure 3.17.

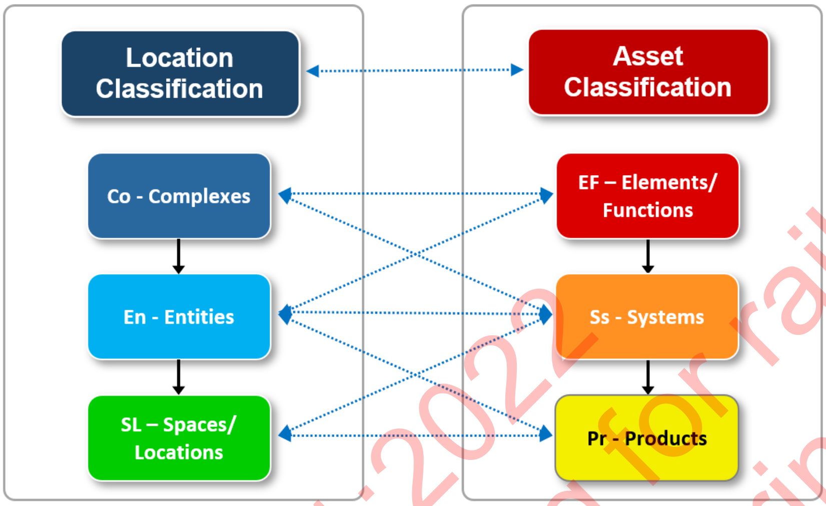


Figure 3.17: Uniclass 2015 - flexible modelling conventions

Uniclass 2015 does not specify how elements, systems and products can or could be combined. This is completely open for users to establish their own conventions and to determine how these are consistently combined.

In practice there are a few general rules that are typically applied as follows:

(a) Systems are generally used as the highest form of asset classification.

(b) The elements / functions (EF) table is generally nonessential and is not always required to support effective asset classification.

(c) Systems may be sub-systems of a parent system.

(d) Products shall always be linked to a parent system.

(e) Complex assets should be broken down and classified at the level of the maintenance managed item (MMI), to inform the infrastructure asset register.

This open and adaptable flexible ontology is much simpler, and is less rigid or hierarchical than many of the other standardized ontologies that are currently used in the built environment e.g. IFC, COBie, ISO15926 - READI, ISO 81346 – Reference Designation Systems, CityML, RailML etc.

This approach is considered to be superior to other current ontologies due to the following:

(a) It requires only the minimum level of granularity, based on specific user need and functionality.

(b) It is flexible and can be universally adapted to suit the broadest range of use-cases.

(c) It negates the need for superfluous data entry, and requires minimal effort to setup and administer.

(d) It can be easily adjusted over the asset lifecycle, to suit variations in scope, roles, owners, technologies etc.

For more information on other existing industry ontologies, refer to comparative undertaken by the Centre for Digital Built Britain (CDBB) A Survey of Industry Data Models and Reference Data Libraries (2020).

3.11 Example case-study using this flexible ontology

The Transport for NSW (TfNSW) DE Framework has adopted this approach, with Uniclass 2015 being central for classification and modelling of physical assets. The following examples are referenced from the TfNSW DE Framework documentation and demonstrate how this form of classification and modelling is applied in practice.

For example, modelling a CCTV system located at a railway station.

This example provides two equally valid methodologies for modelling the physical assets:

(a) Option 1: Basic modelling

High-level classification, supplemented with associated records

(b) Option 2: Detailed modelling

More granular and complete location and asset classification

These two options are explained in further detail:

Option 1: Basic modelling

Referring to Figure 3.18, the CCTV system is broken down into specific assets; however the system is assigned to the railway station (Chatswood Station) at a high-level (A), without specific locations of the individual assets within the station.

In this example more specific location details are provided by supplementing the asset record with an appropriate design model or drawing, which would indicate the precise location of each physical assets.

The model would be stored in the common data environment, with detailed metadata provided to relate the model to the location and the system (relationships B1 and B2).

Option 2: Detailed modelling

Referring to Figure 3.19, each physical asset within the CCTV system is assigned a specific asset location. This method results in the most accurate representation of where to located assets.

The decision of whether to adopt a basic versus detailed approach for the project should be assessed based on the user needs e.g. design team, O&M team etc.

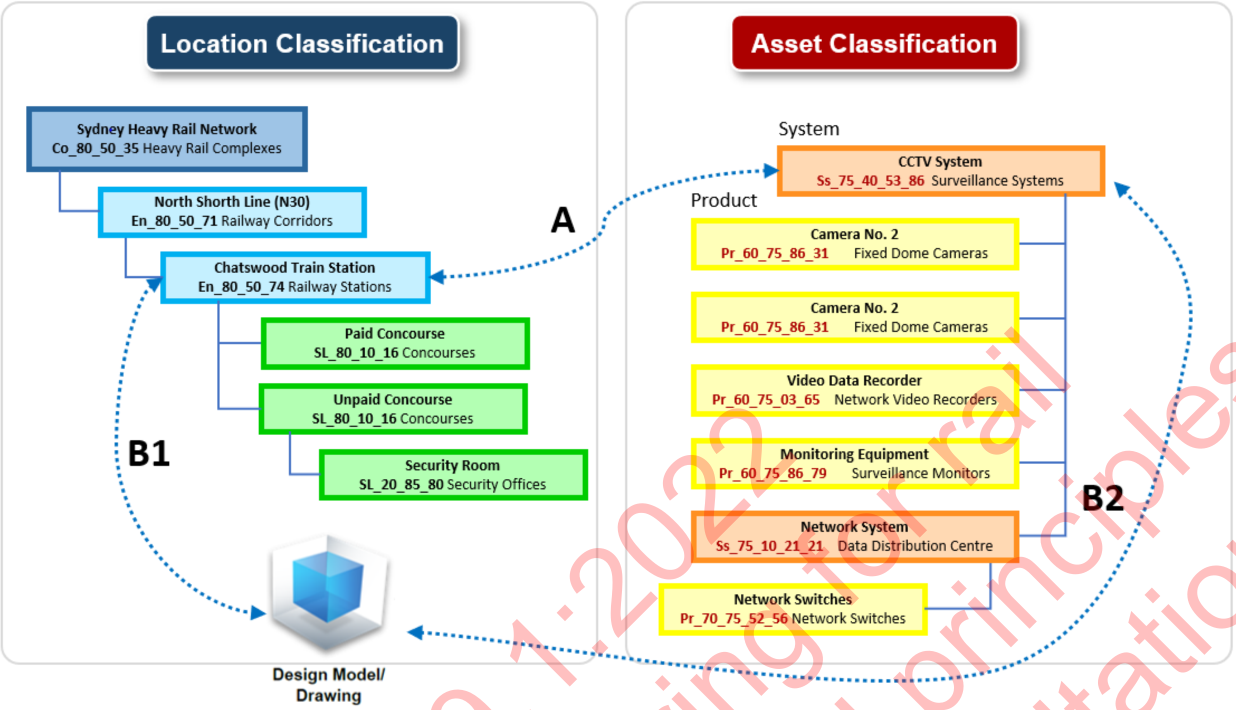


Figure 3.18 Classification example - Option 1: Basic modelling with supplementary records

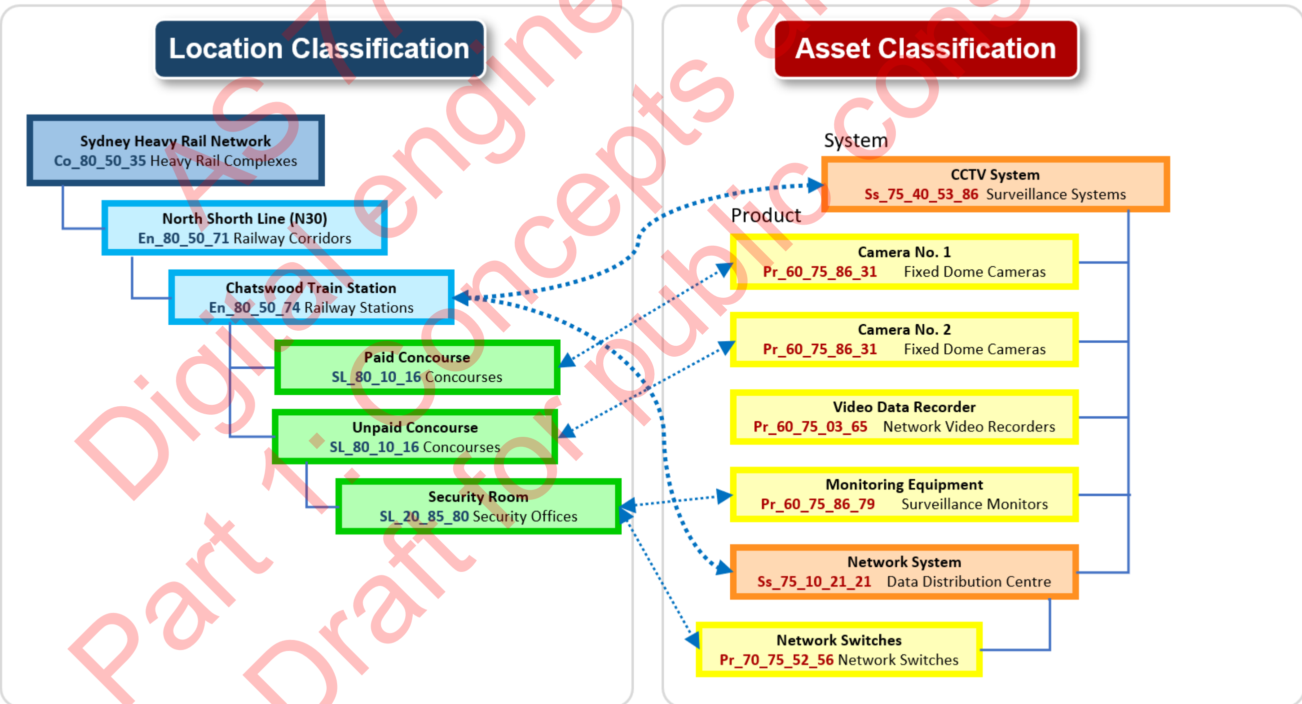


Figure 3.19 Classification example - Option 2: Detailed modelling

Further examples the demonstrate the implementation of Uniclass 2015 are provided in Appendix C, including the following:

(a) Heavy rail – track components.

(b) Light rail – station ticket vending machines.

(c) Motorway – kerb and pavement.

(d) Building – internal fittings.

4 Data modelling to support DE

4.1 Introduction to data architecture

According to the Data Management Body of Knowledge (DMBOK), data architecture includes specifications used to define data requirements, guide data integration, and control data assets as put forth in a data strategy.

Standardized data classification and modelling are essential for enabling DE, however in isolation these elements alone are not enough to support a fully functioning connected digital ecosystem (CDE 2.0). A broader set of data requirements are necessary, that defines the complete data architecture and enables the digital ecosystem to support DE over the complete digital asset lifecycle.

Data architecture plays a fundamental role in the development of DE solutions. It provides the necessary tools and capabilities for analyzing and designing of the data stored in information systems, with particular focus on concentrating on data entities, their attributes, and their relationships.

4.2 Data management concepts

The shift towards digital ways of working requires a variety of new data-related capabilities, that are not commonly found within the infrastructure sector.

Referring to Table 4.1, there are a series of related terms and concepts that together support the data architecture for DE and broader digital transformation. This section expands on these concepts further, explains how they come together to build the digital ecosystem to establish DE over the complete digital asset lifecycle.

Table 4.1: Data management terminology

Term	Definition	Meaning
Dataset	Container or collection of data, that can be manipulated as a single unit	Electronic files and deliverables
Metadata	"*Data about data*" that enables datasets to be structured, managed, and federated	Tags or attributes for organising data
Data schema	A logical blueprint of how a database is constructed e.g., tables, relationships, indexes, views etc	The skeleton or structure of a database
Database	A shared, integrated platform that stores an organized collection of related data.	A way of storing and organising data
Database management system (DBMS)	The computer software program used to manage and query a database.	Database applications
Database Query	A request to access or manipulate data from a database table or combination of tables (e.g. Create, Retrieve, Update,	A way of retrieving and using data

	Delete etc), typically performed using Structured Query Language (SQL).	
Connected Digital Ecosystem	A secure and federated network of consistently structured databases that manages interoperable project/asset data	A digital ecosystem of linked databases

4.3 Database capabilities

A database stores and organizes a collection of data using an accessible and shared platform. A database management system (DBMS) is commonly defined as a computer software program used to manage and query a database.

Key functionalities provided by DBMS typically include the following:

(a) Data storage, retrieval, and update.

(b) User accessible catalogue or data dictionary describing the metadata.

(c) Facilities for recovering the database if it becomes damaged.

(d) Support for authorization of access and update of data.

(e) Access support from remote locations.

(f) Enforcing constraints to ensure data in the database abides by certain rules.

Users access and interact with data stored in DBMS using agreed database query languages, with the most common form being structured query language (SQL). Database queries support all forms of interaction with structured data such as creating, searching, updating, and reporting. They allow users to efficiently handle vast quantities of structured data from multiple sources using rapid, relatively simple sets of commands.

Database queries provide a vastly improved method of managing and interacting with data. Datasets can be identified, retrieved, and analysed faster than ever before, replacing menial tasks with automation, and enabling insights from a variety of sources both efficiently and accurately. In many ways, database queries are the powerhouse behind digital transformation, that deliver a step change in business productivity and performance.

In the context of DE, the use of databases and queries introduce new capabilities. Through the use of managed databases, data becomes more quickly accessible, verifiable, and re-usable – thereby optimising business processes for numerous parties, for numerous use cases, over the complete asset lifecycle.

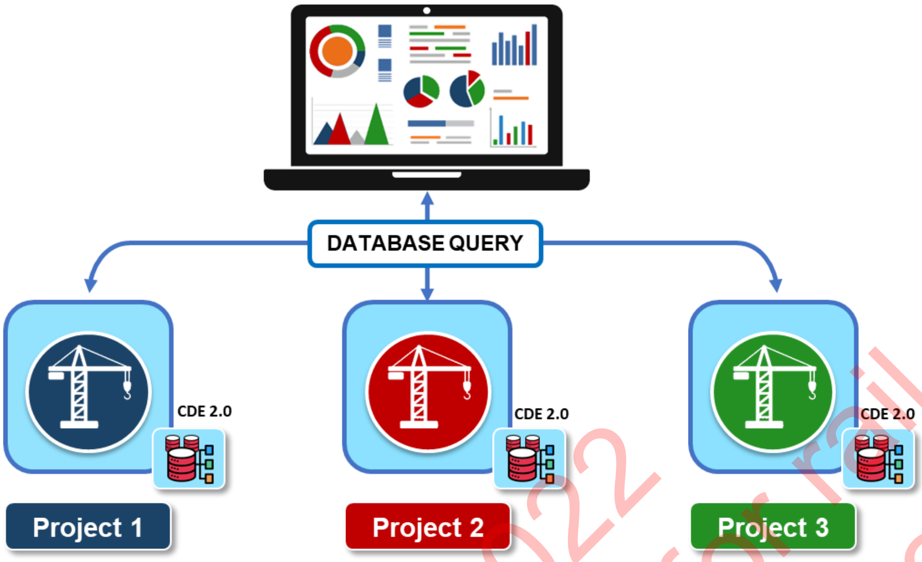


Figure 4.1: A portfolio view, supported by database queries

Most significantly, data can be federated and analysed from a diverse range of structured datasets, providing a portfolio view across a range of projects as represented in Figure 4.1.

4.4 Data schemas and databases

Data schemas define the structure of relational databases that, in turn, are used to store an organized collection of related data. Data schemas play a key role in maintaining effective data management, by specifying metadata requirements for datasets. They ensure the integrity of metadata structures is maintained and supports semantic interoperability between information systems.

In short, the combination of consistent metadata, stored in agreed data schemas creates structured data.

In the context of DE, specialized data schemas are required for each type of dataset managed within the CDE 2.0. All DE data schemas contain a combination of high-level and specific metadata requirements, to support the broad range of use-cases for various information deliverables.

Standardized data schemas are an essential part of consistent, industry wide DE implementation. The first step to creating agreed data schemas, is to establish data models that capture critical aspects of the data architecture over the full asset lifecycle.

4.5 Data modelling

4.5.1 General principles

Data modelling is typically considered to be the first stage in designing a database. It can be defined as the process of analysis and design, based on defined data requirements, to build a data model along with the accompanying libraries of associated metadata. The resulting data model should address specific (and typically complex) real-world problems, that involve information management and exchange.

A data model is a relatively simple representation, usually graphical, of more complex real-world data structures. In general terms, a model is an abstraction of a more complex real-world object or event. A model's main function is to breakdown and understand the complexities and inter-relationships that exist real-world environment. The resulting model users' data requirements, usually expressed in the form of an ERD.

Within the database environment, a data model represents data structures and their characteristics, relations, constraints, transformations, and other constructs with the purpose of supporting a specific problem domain.

Referring to Figure 4.2, there are three main types of data models, that are developed in sequence, as the level of definition incrementally improves.

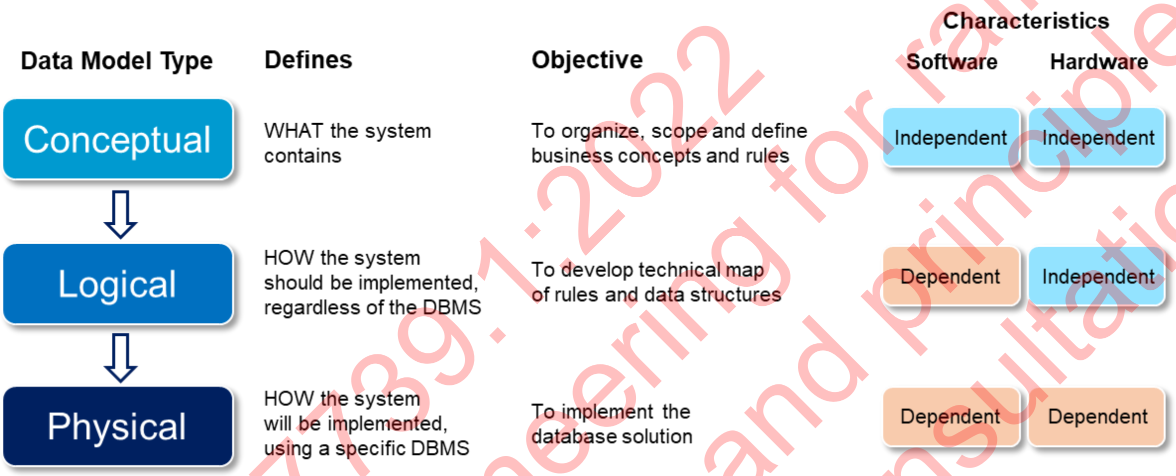


Figure 4.2: Types of data models

To create the initial conceptual data model, data modellers typically build ERD, which are explained in detail in the next section.

4.5.2 Entity-relationship data models

An entity- relationship diagram (ERD) is a graphical diagram, that represents an underlying entity-relationship data model. It is used to communicate the key aspects of the model in terms of real-world data entities, their attributes and their business relationships between associated entities.

Data modelling through the use of ERD's is a practice that was first established in the early 1970's. This approach is commonly used today by data modellers and database designers. In the rail and broader infrastructure sector, it is still relatively new and is uncommon even in industry leading organisations.

ERD's comprise a variety of specific terms and definitions, as listed in Table 4.2.

Table 4.2: Entity-relationship diagram terminology

Term	Definition
Entity	A real-world ‘thing’ (e.g. object, person, idea or concept) with attributes
Attribute	Characteristics or properties of an entity
Relationship	Dependency or association between two entities
Constraint	A restriction placed on data, usually expressed in the form of business rules e.g. “Quality rating needs to be between 0 and 5 stars.”
Primary key	An attribute that uniquely identifies an instance of the entity
Foreign key	An attribute that references a primary key from another entity, thereby linking two entities
Composite key	A key that is made up of more than one attribute.
Cardinality	Specifies how many instances of an entity relate to one instance of another entity (1:1, 1:Many, and Many:Many)

Data modelling can be undertaken using a variety of methodologies and notations, each with their various strengths and weaknesses. For more details on the various ERD methodologies refer to the Data Management Body of Knowledge (DAMA International, 2nd Edition 2017).

This Standard recommends the use of Information Engineering (IE) (also known as a crows-foot) notation. This method was developed in the 1980’s and is the predominant form commonly used by most data modelling software applications. This using the following conventions for modelling entities, their data and their inter-relationships, as presented in Figure 4.3.

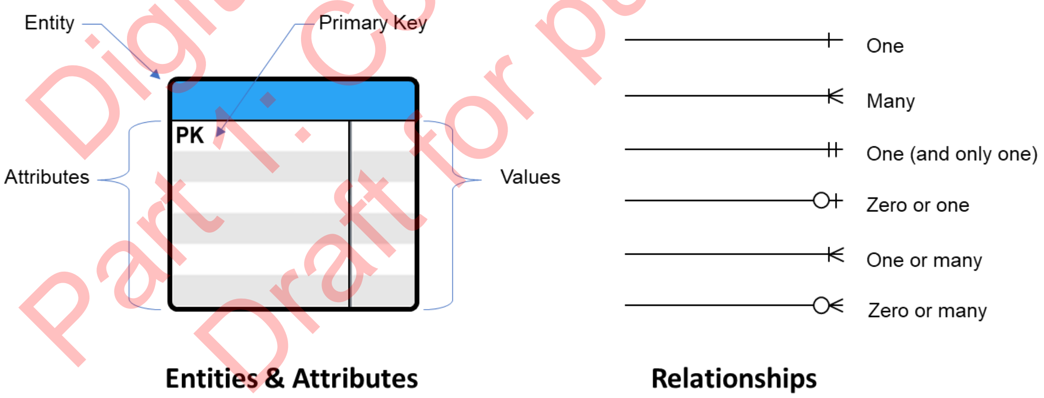


Figure 4.3: Data modelling conventions

The relationships between attributes are established using keys. All entities shall have at least one attribute that specifies a unique identifier in the form of a primary key. The primary key shall be machine readable and specific only to that entity.

Entities can reference primary keys from other entities in the form of foreign keys This is used to indicate relationships between entities that are represented as lines between entities. The symbols at the ends of the lines are labelled the cardinalities which are used to indicate and describe the nature of the relationship between the entities. New primary keys can also be formed by combining multiple attributes, otherwise known as composite keys.

Referring to Figure 4.4, this ERD provides a very simple data model for online shopping, denoting the data requirements to track how a customer would order a product.

Figure 4.4: Example of a simple ERD

5 DE Business Setup

5.1 Introduction

In the previous sections of this Standard, DE key concepts have been introduced and explained in detail. This section of the standard begins to combine all of concepts and principles together and provides a high-level explanation on how they are put into practice, in the form of a standardized data model.

A standardized data model is crucial for enabling efficient and reliable data exchange between parties throughout the ANZ rail industry. The following section introduces a standardized conceptual data model and covers the following key topics (also presented in Figure 5.1):

(a) Conceptual Data Model for DE.

(b) Introduction to Master Data Entities.

(c) Introduction to General/Specialist Entities.

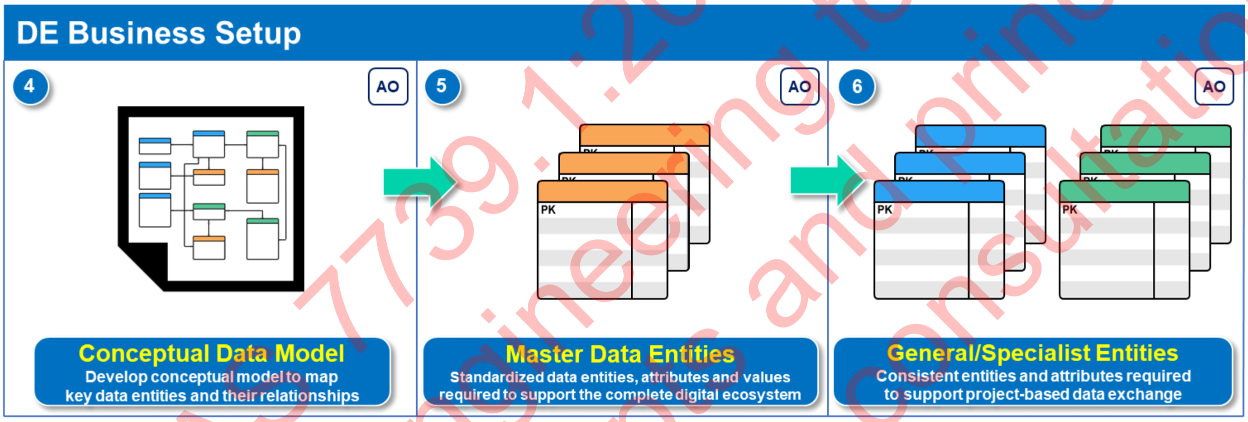


Figure 5.1: Key subjects covered in Section 5 DE Business Setup

It is noted the primary audience for this section is rail infrastructure asset owners, as this outlines the organizational setup required for successful specification and delivery of DE deliverables on major infrastructure projects.

5.2 Data modelling conventions to support DE

Before explaining the key concepts of data modelling, it is first necessary to define the conventions necessary for describing the breakdown of the data model components. Referring to Figure 5.2, this diagram represents the breakdown of the data model, from high-level groups down to specific attributes and their associated business rules. Comparisons of these conventions may be made with Uniclass 2015, and its standardized breakdown of asset types and their locations.

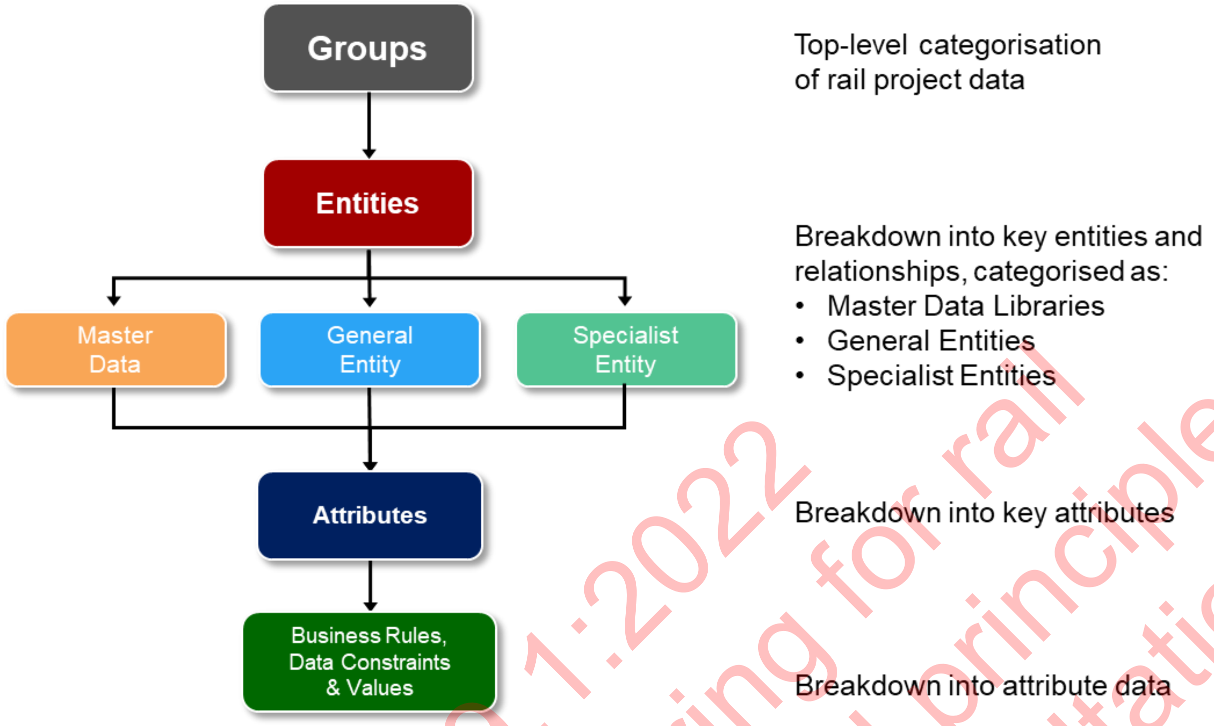


Figure 5.2: Data modelling conventions to support DE

This section of the Standard does not try to define the specific data model that is required to standardize DE for the ANZ rail industry. The content in this section introduces and explain the concepts and principles associated with data modelling only.

A more detailed data model is presented in AS 7739.2 This model provides detailed specification of data attributes, unique identifiers and relationships between key entities, defining the necessary and appropriate level of standardization for the ANZ rail industry.

5.3 Conceptual data model

5.3.1 Data model – entity groups

The conceptual data model comprises ten main groups, as presented in Figure 5.3.

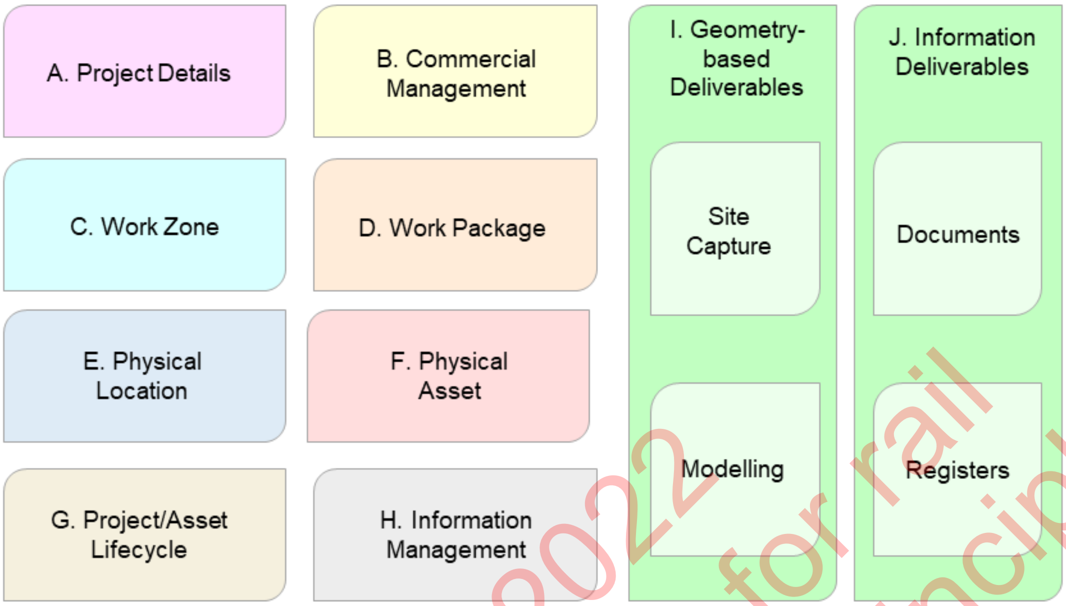


Figure 5.3: Data model – Entity Groups

Each of the groups are listed in Table 5.1

Table 5.1: Data model - entity groups

Entity group		Details
A	Project details	Overall program and breakdown of discrete projects
B	Commercial management	Breakdown of project contracts and associated organizations
C	Physical work zones	Breakdown of temporary physical locations assigned during project delivery
D	Work packages	Breakdown of physical works and services into discrete packages
E	Physical location	Breakdown of physical locations of assets
F	Physical asset	Breakdown of physical infrastructure assets and sub-components
G	Project / asset lifecycle	Key stages and milestones over asset lifecycle
H	Information management	Conventions based on ISO 19650
I	Geometry-based deliverables	Key project datasets that feature geometry-based information, grouped together as either site capture or modelling
J	Information deliverables	Key project datasets, grouped together as either documents or registers

5.3.2 Data model – entity types

Data model groups are broken down into three types of entities as listed in Table 5.2

Table 5.2: Data model – entity types

Entity Type	Entities that are:	Example:
Master Data	standardised across rail industry or jurisdiction	Asset classification
General Entity	shared across multiple types of datasets	Project code
Specialist Entity	specific to a single type of dataset	CAD layers

5.3.3 DE conceptual data model

It is recommended a DE conceptual data model is developed based on some of the initial modelling provided in Figure 5.4 and Figure 5.5. These diagrams introduces the overall structure of the standardized data model and introduces the high-level relationships between the key entities (note for simplicity this diagram does not present all entities or relationships).

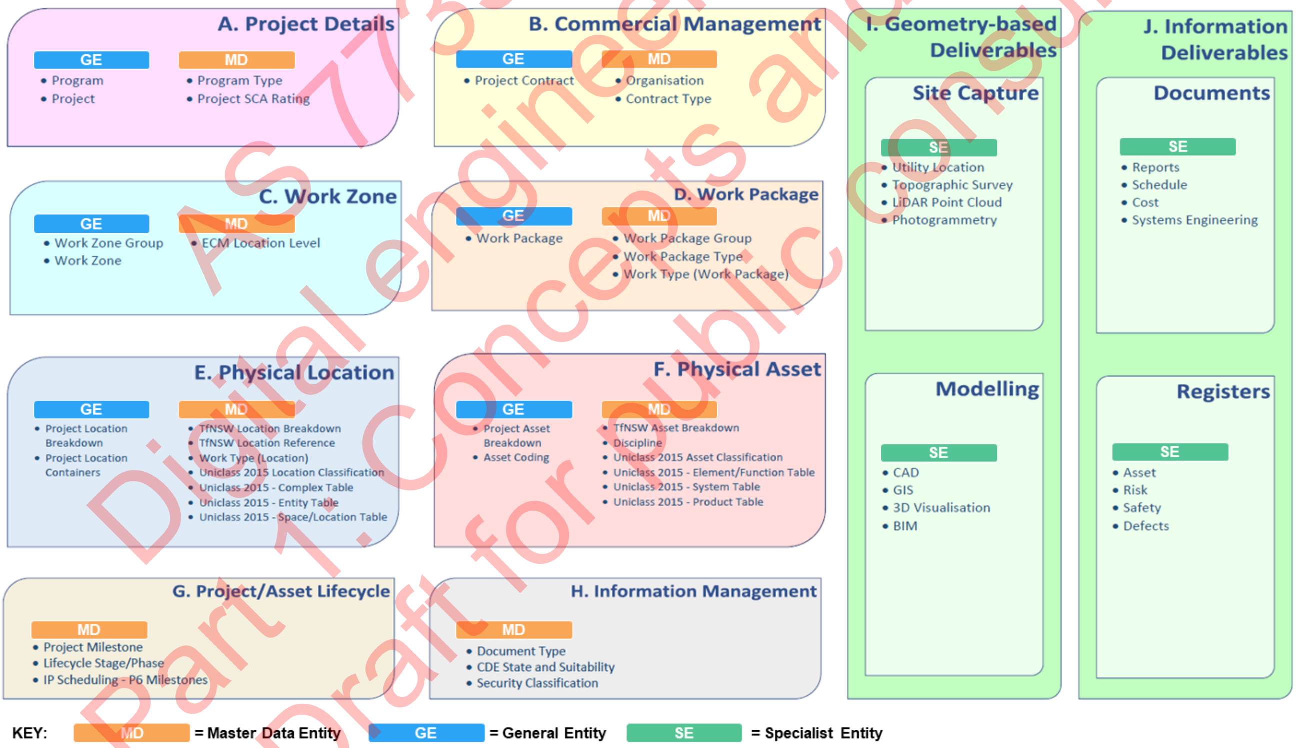


Figure 5.4: DE Conceptual data model (preliminary)

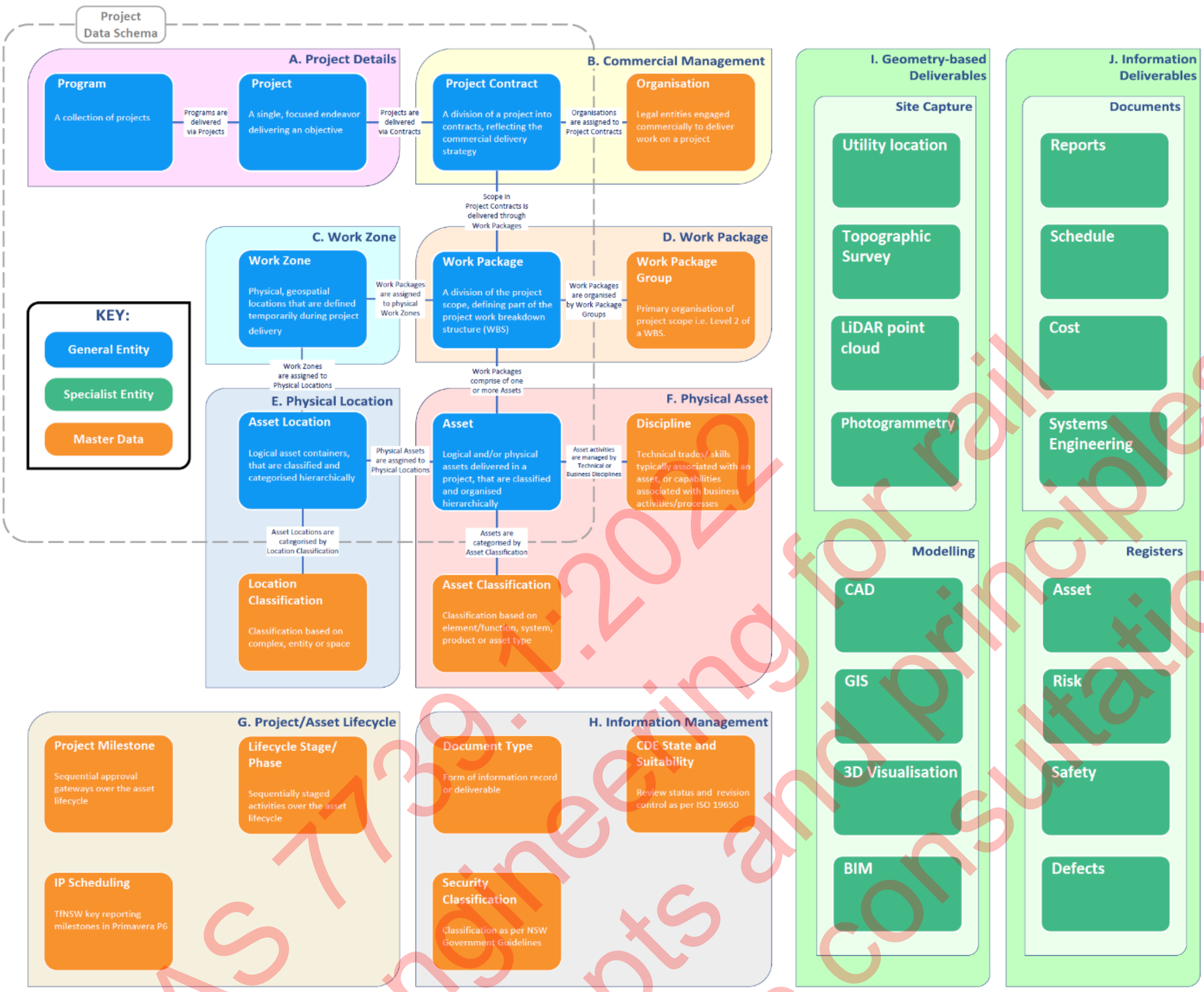


Figure 5.5: Representation of a more detailed data model

5.4 DE data entities

5.4.1 Introduction

This section covers some of the key data entities required to support DE project delivery. The tables in the section are not exhaustive and are provided only to introduce the concepts and explain the overarching process.

These lists are not exhaustive and are further explored in AS 7739.2. which provides more detailed information on DE data entities, relationships, associated attributes and business rules

5.4.2 Data model – master data entities

Master data entities should be completely standardized, with consistent entity names, attributes relationships and business rules to enable and support the complete digital ecosystem. All master data shall be machine readable, to enable automated data exchange and re-use for all parties throughout the digital ecosystem, over the complete asset lifecycle.

Refer to Table 5.3 for master data entity examples.

Table 5.3: Data model – master data entities

Group		Master data entity	Description
A	Project details	Program type	Standardized program categories based on mode, scope etc.
		Project SCA rating (Safety Change Assessment)	Project rating based on safety change impact assessment, as part of broader network configuration controls.
B	Commercial management	Organization	Legal entities engaged commercially to deliver work on a project
		Contract type	Forms of contracts, reflecting the commercial delivery strategy
C	Physical work zones	ECM location level	Three-level grouping to define location breakdown within ECM
D	Work packages	Work package group (WPG)	Primary organization of project scope i.e. Level 2 of a WBS.
		Work package type	Secondary organization of project scope i.e. Level 3 of a WBS.
		Work type (Work package)	Work type categories to inform composite benchmark rates (e.g. install, replace, refurbish etc)
E	Physical location	Asset owner location breakdown	Breakdown of existing infrastructure locations based on Asset Owner hierarchy
		Asset owner location reference	Asset owner labelling/naming for existing asset locations, categorized by complex, entity or space
		Uniclass 2015 location classification	Classification based on complex, entity or space
		Uniclass 2015 - Complex table	Highest level grouping of built environment facilities or infrastructure networks
		Uniclass 2015 - Entity table	Breakdown of complexes into independent units, categorized by form, function or user activity
		Uniclass 2015 – Space / location Table	3D areas designated for specific activities or functions to take place. Also used to divide the asset into suitable sections.
		Work type (Location)	Work type categories to inform global benchmark rates
F	Physical asset	Asset owner asset breakdown	Breakdown of new infrastructure assets based on asset owner hierarchy (for asset handover)
		Uniclass 2015 asset classification	Classification based on element / function, system, product or asset type
		Uniclass 2015 – Element / function table	Elements: Main components of a structure Functions: Services provided/managed by an asset
		Uniclass 2015 - System table	Breakdown of built environment into independent systems that perform specific functions
		Uniclass 2015 - Product table	Individual maintainable assets, that work collectively form a system

		Discipline	Technical trades/ skills typically associated with an asset, or capabilities associated with business activities/processes
G	Project / asset lifecycle	Project Milestone	Progressive approval gateways over the asset lifecycle
		Lifecycle stage / phase	Progressive activity stages over the asset lifecycle
		Scheduling reporting milestone	Key reporting milestones in Primavera P6
H	Information management	Document type	Form of information record or deliverable
		CDE state and suitability	Review status and advanced revision control as per ISO 19650
		Security classification	Classification as per jurisdictional or agency information classification, labelling and handling requirements

5.4.3 Data model – general entities

General entities are consistent entities and attributes required to support project-based data exchange. These entities are typically shared across numerous types of project datasets and should be standardized where required.

Refer to Table 5.4 for master data entity examples.

Table 5.4: Data model – general entities

Group		General Entity	Description
A	Project details	Program	A collection of projects
		Project	A single, focussed endeavour delivering an objective
B	Commercial management	Project contract	A division of a project into contracts, reflecting the commercial delivery strategy
C	Physical work zones	Work zone group	Grouping of project work zones
		Work zone	Physical, geospatial locations that are defined temporarily during project delivery
D	Work packages	Work package	A division of the project scope, defining part of the project WBS
E	Physical location	Project location breakdown	Breakdown of new infrastructure locations based on project nominated hierarchy
		Project location containers	Logical asset containers, that are classified and categorized hierarchically
F	Physical asset	Project asset breakdown	Breakdown of asset components based on consistently structured hierarchy
		Asset coding	Logical and / or physical assets delivered in a project, that are classified and organized hierarchically

5.4.4 Data model – specialist entities

Specialist data entities provide highly technical attributes and relationships that are relevant only to specific DE project datasets e.g. CAD, BIM, GIS etc each of specific attributes that .are relevant only to their own type of dataset.

The conceptual data model groups these specialist entities into the following categories:

(a) Geometry based deliverables;
 i. site capture;
 ii. modelling.

(b) Information deliverables;
 i. documents;
 ii. registers.

The level of detail and specification of specialist entities is provided in AS 7739.2.

6 DE project planning

6.1 Introduction

This section provides advice for asset owners, planning to undertake DE on rail infrastructure projects. Key topics in this section include (also presented in Figure 6.1):

(a) project scoping;

(b) project datasets;

(c) project data models.

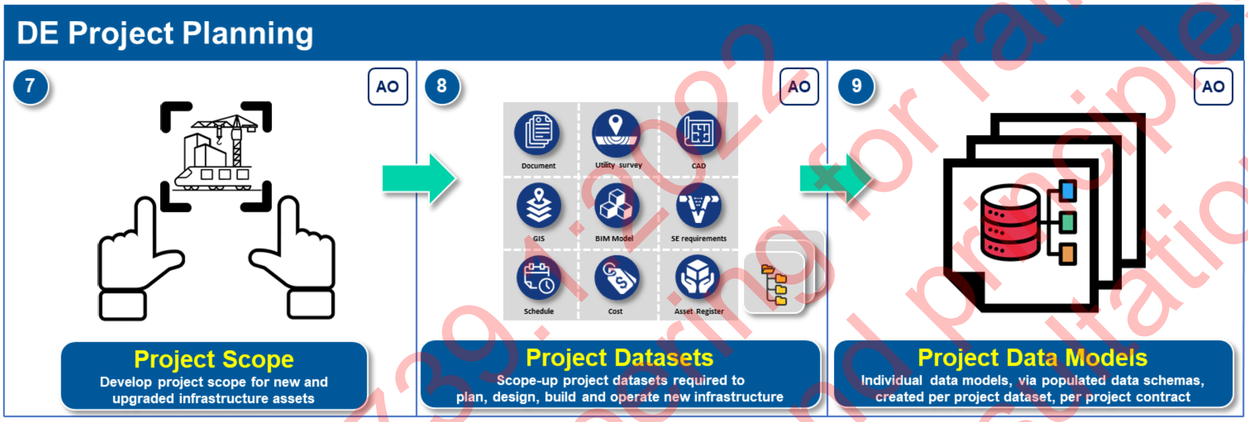


Figure 6.1: Key topics presented in Section 6 DE Project Planning

6.2 Scoping rail infrastructure projects

6.2.1 Complexity of rail infrastructure

Rail networks are complex environments that feature numerous interconnected systems, assets, interfaces and operations. Rail corridors contains numerous types of infrastructure assets that are unique to the railways, that require specialized systems, processes and discipline knowledge over the complete asset lifecycle, as represented in Figure 6.2.

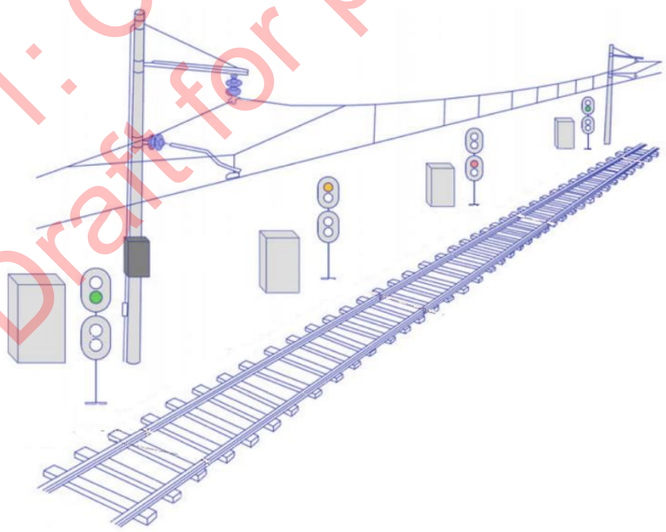


Figure 6.2 Examples of infrastructure assets that are unique to railways

Planning and delivery of rail infrastructure requires unique skills, across a broad range of engineering disciplines including, but not limited to the following:

(a) Civil engineering.
(b) Structural engineering.
(c) Permanent way engineering.
(d) Overhead wiring engineering.
(e) Mechanical engineering.
(f) Electrical (HV/LV) engineering.
(g) Earthing & bonding engineering.
(h) Signalling engineering.
(i) Communications engineering.
(j) Rollingstock engineering.

Rail infrastructure projects typically involved numerous stakeholder parties, often with completing requirements that are relevant at specific stages of the overall asset lifecycle. Project teams therefore have to balance the needs of project delivery, operations and maintenance to ensure optimal asset management outcomes.

6.2.2 Managing project complexity with systems engineering

Managing and planning for complexity requires robust business processes – particularly in regard to scoping new and upgrade railway infrastructure. It is therefore recommended that asset owners adopt a systems engineering (SE) approach on complex projects.

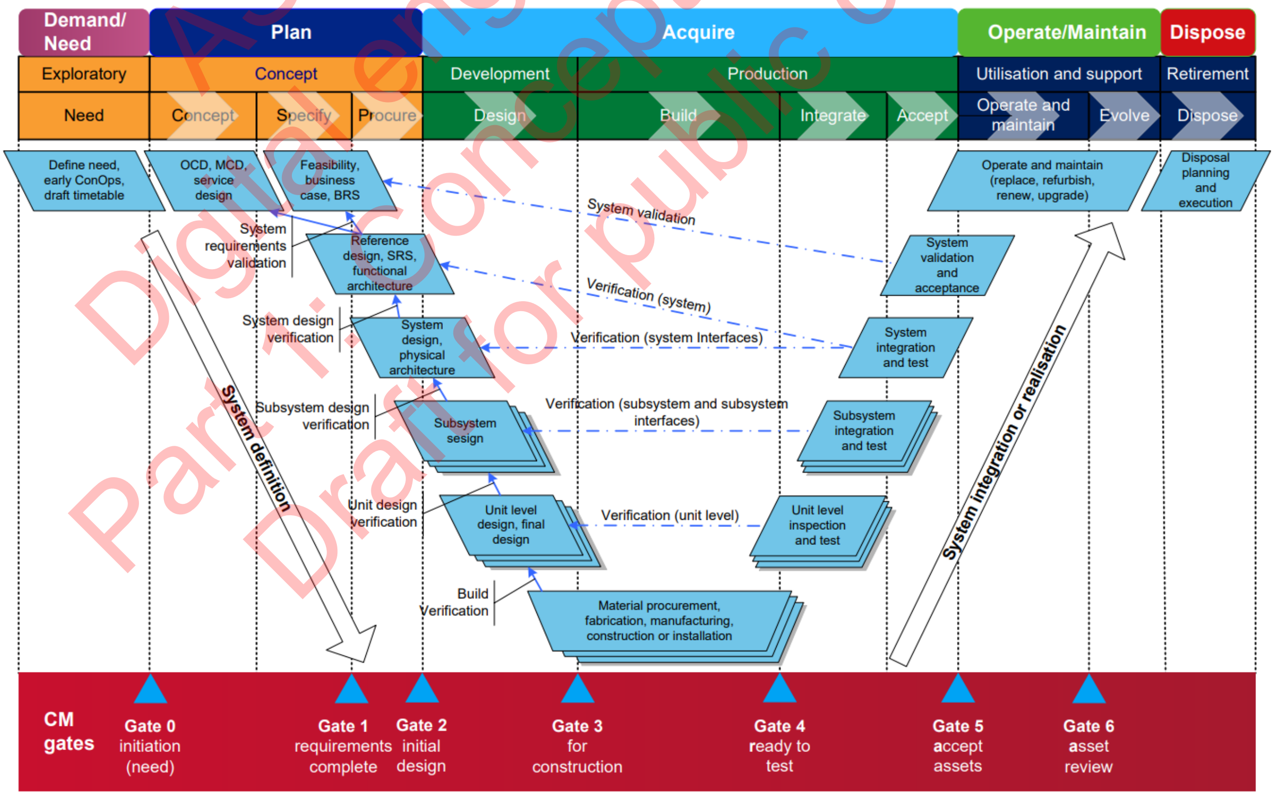


Figure 6.3: System Engineering V-Cycle Model (source: Transport for NSW)

SE can be defined as an interdisciplinary field of engineering and engineering management that focuses on how to define, design, integrate, and manage complex systems over their life cycles. At its core, SE utilizes systems principles and concepts to understand and to organize this body of knowledge. It starts with what the users of the system needs, then what the system needs to do to satisfy the user needs, then how the system will logically work to meet the needs and finally how the system will be built and integrated. The outcome of such efforts, an engineered system, can be defined as a combination of interconnected components that work in synergy to collectively perform a useful function. This is managed incrementally using the SE V-Cycle as in Figure 6.3.

All engineering data must describe the same system outcome and thus be consistent across the lifecycle stages. Visually, the data contained in the SE V-Cycle Model above can be shown in Figure 6.4.

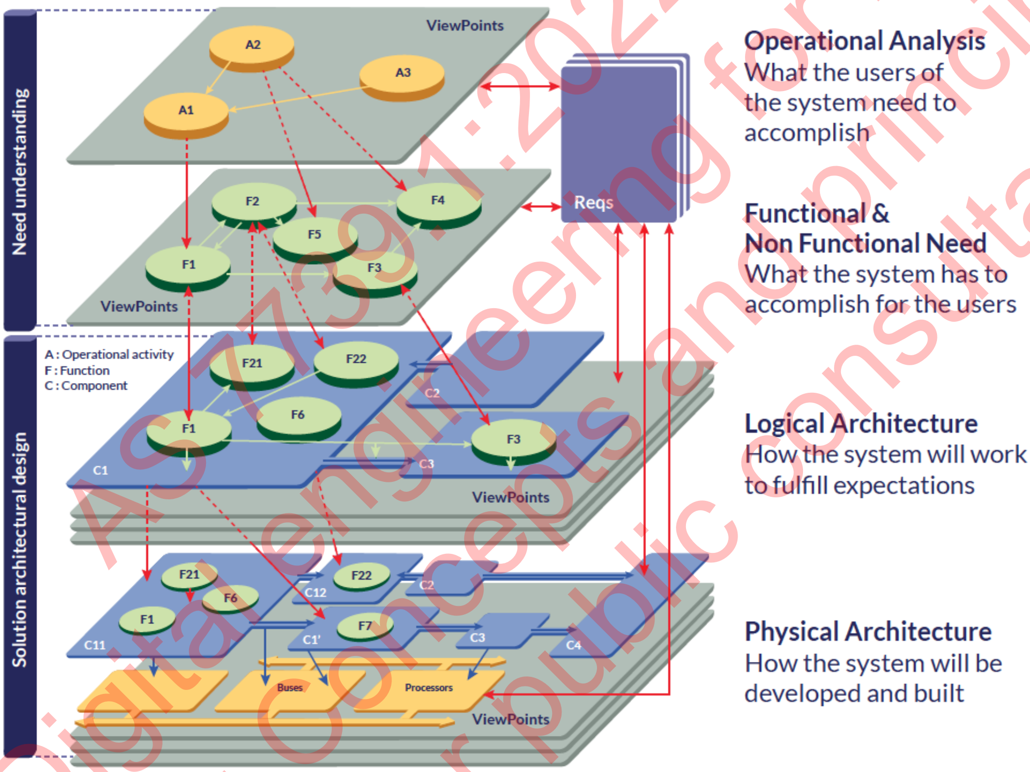


Figure 6.4: Example SE process for needs analysis and solution architecture design

(Source: https://www.eclipse.org/capella/arcadia.html)

The physical architecture and requirements will typically link with other physical models such as BIM/GIS/software development models in a federated database.

This Standard does not provide detailed instructions on how best to adopt and implement a SE approach, as there are numerous other standards that cover this topic. That said, clients should establish business and systems requirements on commencement of all major rail infrastructure projects. This would typically be completed in line with development and approval of the strategic and final business case for major projects.

6.3 Project datasets to support rail infrastructure sector

Once the project scope has been determined and approved, the next step is to scope-up the necessary information deliverables, in the form of datasets, that are necessary for project and asset management. Consideration of key datasets is essential at each stage of the project lifecycle to support planning, design, delivery and handover of new and upgraded infrastructure.

This exercise should consider opportunities for data sharing, re-use and federation, to maximize benefits and opportunities with key project datasets.

Key project datasets include, but are not limited to, the following:

(a) Requirements database
(b) Model-Based Systems Engineering (MBSE) models – includes system (functional and physical) architectures Site surveys of above and below-ground features (inc. utilities).
(c) Geotechnical surveys.
(d) 3D point clouds (if laser scanning is undertaken on the project).
(e) Documents (e.g. design reports, construction certification, operational readiness documentation etc).
(f) 2D CAD drawings.
(g) 3D BIM models.
(h) GIS databases.
(i) Project schedules.
(j) Cost estimates.
(k) Project registers, including (but not limited to):
i. requirements registers (for systems engineering).
ii. asset registers.
iii. risk registers.
iv. safety registers.
v. defects registers etc.

It is noted that asset owners seeking to deliver projects with DE should consider how best to structured metadata into the datasets. Examples include, but are not limited to, those listed in Table 6.1.

Table 6.1: Examples of structured data for different datasets

Dataset	Examples of structured data
Systems engineering	• Classification of systems • Links to engineering standards
2D/3D GIS	• Strings • Metadata • Shape files

Surveys	• Labelling of survey strings • String metadata
CAD	• Labelling of CAD layers • Title block
Scheduling	• Classification in WBS
Cost management	• Classification in cost breakdown structure • Cost estimating & benchmarking
BIM	• Classification of model objects • Model layer federation & aggregation
Document management	• Classification in document metadata
Asset data handover	• Classification of assets & locations • Asset information requirements

6.4 Project data models

Once the project scope has been established and the relevant project deliverables scoped up, the next step is to develop the DE project data models for the project. These data models are typically bespoke and created specifically for each individual type of project dataset, for each project contract.

The project specific data models essentially create data schemas, that itemise the relevant known project data, based on the project scope in a codified form, to populate the necessary entities and attributes in the overarching data model. These are often created using MS Excel, as this is a simple and familiar software platform that is accessible to everyone.

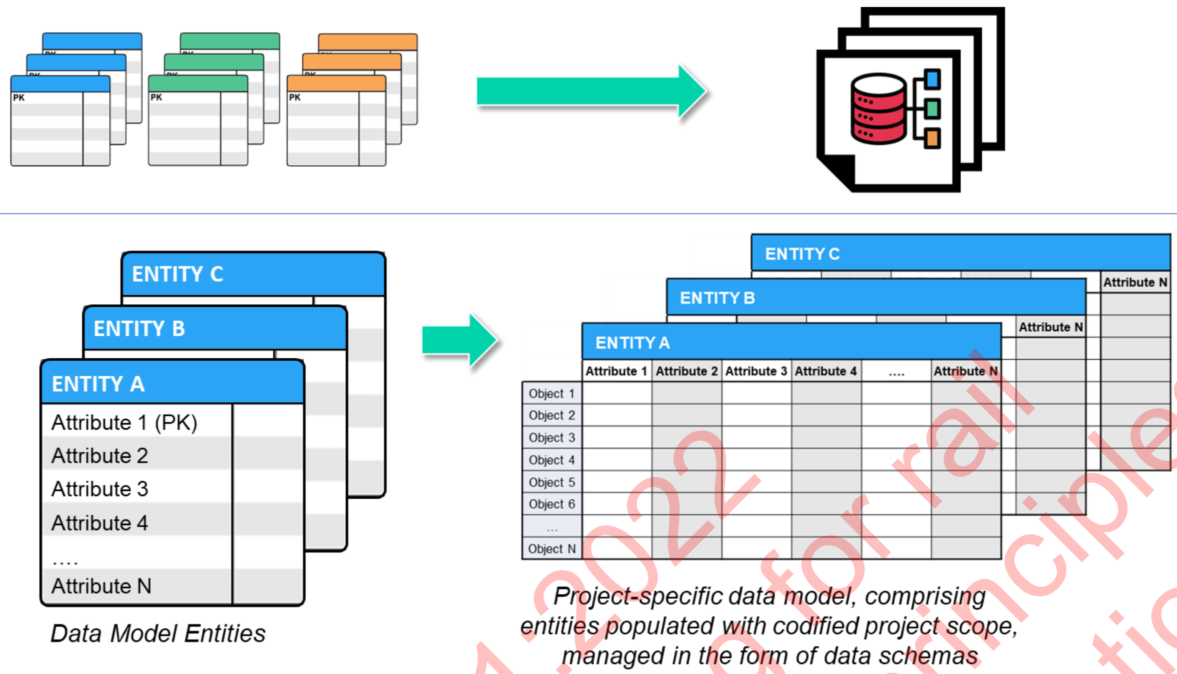


Figure 6.5: Building project data models, in the form of data schemas

The DE project specific data models are created and verified prior to project commencement, and typically form part of the project documentation for procurement of project delivery partners. It is therefore the asset owner's responsibility to create these project data schemas (PDS) upfront that should be included in the project specifications and made available for tenderers to assess and respond.

Further details on the process of building DE project data models are provided in AS 7739.2

7 DE project delivery

7.1 Introduction

This section provides advice for asset owners, planning to undertake DE on rail infrastructure projects. Key topics in this section include (also presented in Figure 7.1):

(a) project procurement;

(b) digital project deliverables;

(c) structured datasets.

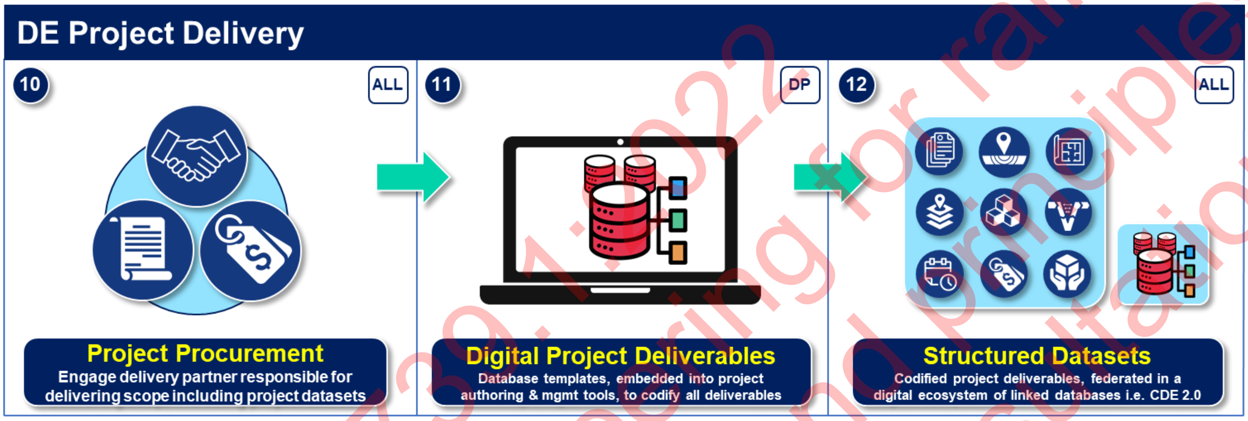


Figure 7.1: Key topics presented in Section 7 DE Project Delivery

Detailed activities and technical requirements for managing DE during project delivery are covered in detail in AS 7739.2

High level introductions to each of these three subjects are provided in the following sections.

7.2 Project procurement

Action owner: All stakeholders

Role: Project team & DE Manager

Summary: Engage delivery partner responsible for delivering scope including project datasets.

Details: Upon completion of the procurement process, further work could be required to update and/or revise the PDS with the winning tenderer. Once final changes are formally agreed, the PDS for each form of dataset is essentially locked in place, to ensure all metadata is controlled going forward.

7.3 Digital project deliverables

Action owner: Delivery partner

Role: Digital engineer(s)

Summary: Database templates, embedded into project authoring & management tools, to codify all deliverables

Details: The project partner (e.g. designer, builder etc) is to install the agreed PDS into their project authoring & data management tools. The project teams are then to tag all subsequent project deliverables with the PDS, to ensure correct metadata is applied to all respective project datasets.

7.4 Structured datasets

Action owner: All stakeholders

Role: DE manager & digital engineer(s)

Summary: Codified project deliverables, federated in a digital ecosystem of linked databases i.e. CDE 2.0

Details: The delivery partner submits all project deliverables as structured datasets, that are able to be federated within the project CDE 2.0. Structured data is now available as a key resource for all permitted stakeholders, enabling data-driven decisions and insights by all relevant parties.

Appendix A Benefits of DE

Informative

A.1 Benefits of digital engineering

DE provides a range of new capabilities and benefits for project stakeholders across organization, and over the complete asset lifecycle. The opportunities for business improvement through DE are virtually endless, with the following diagrams provided to communicate the benefits of DE through a variety of lenses.

A.2 Project savings – reducing waste and improving productivity

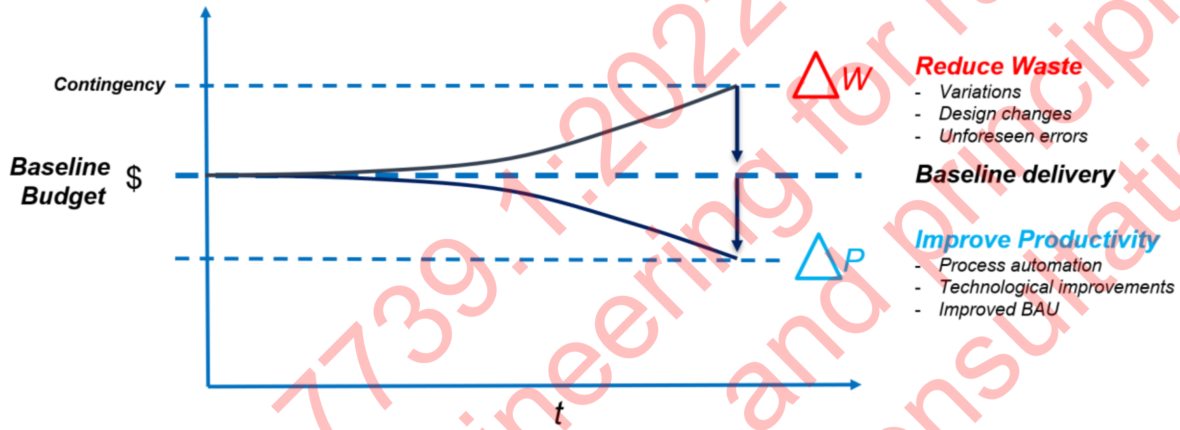


Figure 7.2: Project savings through DE

A.3 Project benefits

Table 7.1: DE benefits over the project lifecycle

Project stage	DE capability	Benefit
Site capture	• Digital survey • Federated GIS	• Improved site data capture • Greater insights and faster decisions
Design	• Project modelling and visualization • Digital deliverables • BIM & GIS specification	• Improved stakeholder engagement • Less reliance on paper drawings • Improved design coordination
Procure	• Accurate project specification • Data driven project controls	• More reliable tender pricing • More reliable project reporting
Construct	• More informed site planning	• Safer work sites

	• Digital deliverables with structured data	• Faster, more efficient asset handover

A.4 Program benefits

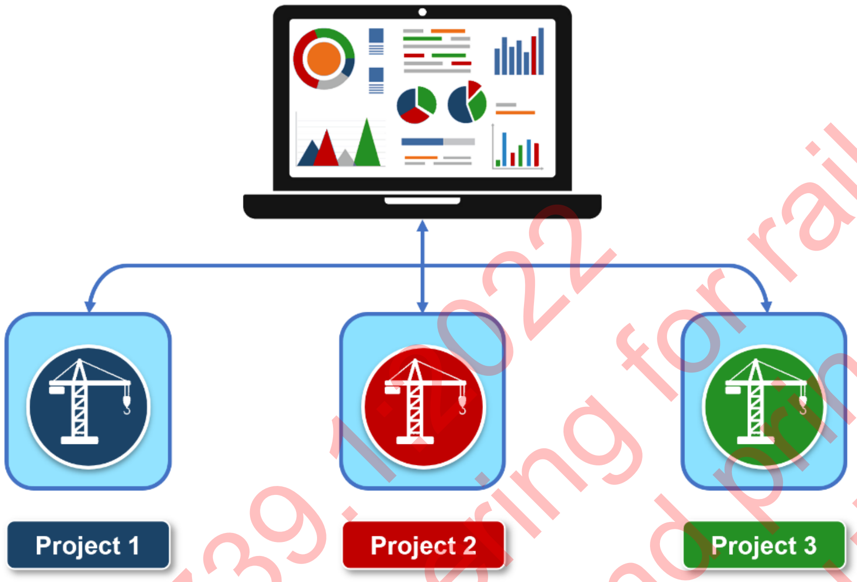


Figure 7.3 DE enables a portfolio view

A.5 Organizational benefits

Table 7.2: Organizational benefits enabled through DE

Capability	Benefit
Collaborative working	• Improved access and sharing of information • Reduced latency for improved decision making
Structured data with open standards	• Consistent, interoperable project data • Enabling federation of data and content re-use
Accessible, reusable information	• Information retrievable when required • Minimizing re-creation of data and information
Design deliverables with 3D models	• Improved, multidisciplinary design co-ordination • Faster, more reliable design for improved constructability
Visualization	• More accurate, reliable project visualization • Improved clarity and stakeholder engagement
Safe working	• Simulation and virtual construction for improve safe working • Safer worksites and improved planning of high-risk activities

Appendix B Overview of ISO 19650

Informative

B.1 Introduction

ISO 19650 is a suite of international standards (released from 2018 onwards) that provides guidance on the use of building information modelling (BIM) to improve information management over the lifecycle of buildings and civil works. These standards have elevated many of the concepts taken from the previous UK BS/PAS 1192 suite of standards (released between 2013-2018), to cater for a broader, more generic international audience.

The set of standards currently comprise of 5 parts:

(a) Part 1: Concepts and Principles (2018)

(b) Part 2: Delivery Phase of the Assets (2018)

(c) Part 3: Operational Phase of the Assets (2020)

(d) Part 4: Information Exchange (2021) (Draft)

(e) Part 5: Security-Minded Approach to Information Management (2020)

Figure 7.4: Generic project and asset information management life cycle

ISO 19650 represents the asset lifecycle in simple terms, provided in Figure 7.4 above. The green circle represents the cyclical nature of information management activities of an asset over the lifecycle as it progresses through delivery (points A to C) and operational phases – and then back again when the assets begin the next round of upgrades.

B.2 Concept of information models

The standard introduces the concept of information models, that comprise of all information required to deliver and manage an asset throughout its lifecycle. This could include geometric data (including 2D drawings and BIM Models), non-geometric data (including spreadsheets and databases) and any other information (for example, email correspondence and documents).

ISO 19650 describes two key information models as follows:

(a) Project information model (PIM)

(b) Asset information model (AIM)

B.3 Project information model

The PIM contains all information used and produced during the planning, design and construction phases of the project. This includes all information deliverables identified in contract documentation including asset owner standards and any other information relied on or used by the Contractor for the development and delivery of the project.

Examples of the types of project management information produced include:

(a) all design engineering information including CAD, BIM (3D models) and GIS information;

(b) temporary works information;

(c) time and scheduling information;

(d) cost management data;

(e) registers such as risk registers, issue registers, interface registers;

(f) safety management information such as safe work method statements, hazards;

(g) environmental information such as key constraints and conditions of approval;

(h) project management data;

(i) all other relevant project information.

B.4 Asset information model

The AIM contains all asset information deliverables produced for use in the O&M phase. Information contributing to the AIM can initially be generated during the project delivery phases and handed over from the project team to the O&M parties as part of a formal acceptance procedure. This information is then built upon by the O&M team as a result of evidence generated during operation and maintenance activities.

Examples of the types of asset information produced include:

(a) handover asset register;

(b) all as-built engineering information including CAD, BIM (3D models) and GIS information;

(c) quality assurance information such as inspection and test plan and manuals;

(d) records of installation and maintenance dates;

(e) property ownership details;

(f) warranties;

(g) residual risks and hazards;

(h) actual delivery costs by asset type and location;

(i) other relevant asset management information for operations and maintenance.

The systems used to structure and store both the PIM and the AIM is collectively referred as the common data environment, which the ISO describes as the agreed source of information for any given project or asset, for collecting, managing and disseminating each information container through a managed process.

Successful handover of information between the PIM and the AIM requires clear definition and alignment of information requirements, as defined in section B.5.

B.5 Information requirements

ISO 19650 introduces the concept of information requirements, as a method of structuring and standardising all data and information that comprises the information model. A client at each stage of the asset lifecycle determines the data and information required to meet their objectives and assist in lifecycle decision-making, as represented in Figure 7.5.

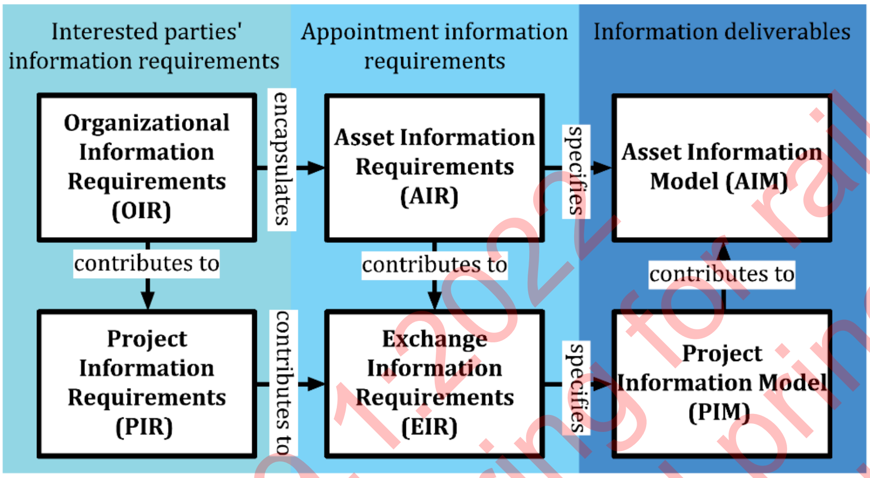


Figure 7.5 Information Requirements that specify Information Models

ISO 19650 defines four levels of information requirements (IR) as follows:

(a) Organizational information requirements (OIR) - IR for organizational objectives

(b) Asset information requirements (AIR) - IR for operation of an asset

(c) Project information requirements (PIR) - IR for delivery of an asset

(d) Exchange information requirements (EIR) - IR for a specific contract

It is the client's role to ensure that all necessary requirements are defined upfront prior to commencement of the project. For more details on establishing information requirements, please refer to Section 5 of ISO 19650.1

B.6 Information management over complete lifecycle

A key diagram of ISO 19650 series (and the prior PAS1192 standards) is provided overpage in Figure 7.6, which represented the information management process over the complete asset lifecycle. Unlike the previous lifecycle diagram presented earlier, this diagram displays the lifecycle in linear form, with time represented along the x-axis from project stage 1 through to end-of-life.

This diagram represents the build-up of project and asset information over the lifecycle, noting the following details:

(a) Blue arrows represent information management processes.

(b) Green sections represent information production (in terms of PIM & AIM).

(c) Information Requirements are specified on commencement of the CAPEX project, as indicated by the OIR, AIR & EIR in the top right.

(d) Generic asset lifecycle stages and gates are represented along with x-axis, using generic labelling i.e. Stages 1, 2, n, etc. and Gates 1, 2, n etc.

This diagram represents how all project and asset information is to be created, managed and exchanged wholly within a common data environment. The CDE manages the key activities including:

(e) gathering existing relevant asset information at project commencement;

(f) collaborative production of the PIM during project delivery;

(g) production and maintenance of AIM during asset management.

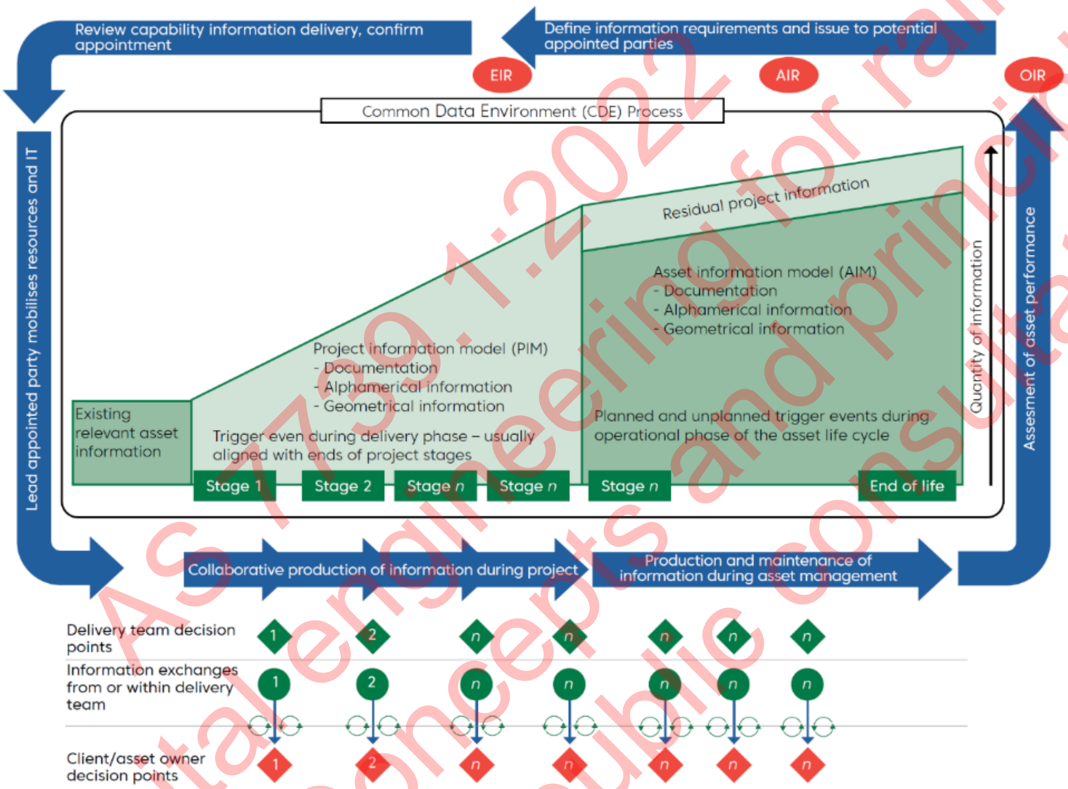


Figure 7.6: Overview and illustration of the information management process

B.7 Information management during project delivery

Over the project delivery lifecycle, the programme is typically broken down into a series of project lifecycle stages e.g. plan – design – build – handover. At each stage, service providers are engaged by the client to deliver services and associated information deliverables.

ISO 19650 refers to the engagement at each lifecycle stage as an appointment and outlines three key activities that are completed during each of the project lifecycle stages.

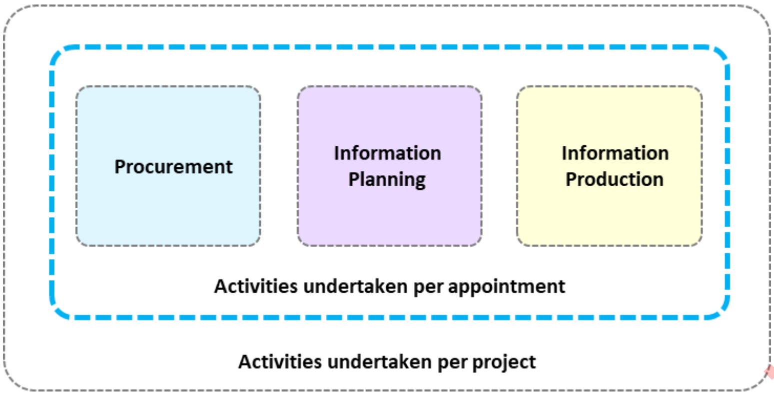


Figure 7.7: Illustration of the sub-division of processes

Referring to Figure 7.7, these three activities include:

(a) Procurement of the appointed party (i.e. service provider) – including invitation to tender and tender response

(b) Information planning – including appointment and mobilization of the service provider

(c) Information production – including collaborative production and delivery of the information model

These three main activities are repeated numerous times, as the project progresses through the lifecycle of project delivery from planning through to completion and asset handover.

ISO 19650 Part 2 builds on this concept by expressing the series of information activities over the project lifecycle. Referring to Figure 7.8, the three key activities are each expanded to two sub-activities. Further activities are added at the start and end of the CAPEX Project, bringing the total number of key activities to eight.

It is most important to recognize however that this diagram is not to be interpreted as a linear, step-by-step process moving from activity 1 through to activity 8. The arrow (highlighted in red) that runs from activity 7 back to activity 2 is labelled *"Information model progressed by subsequent delivery team(s) for each appointment".*

This essentially indicates how the information model is to be progressed by subsequent delivery teams for each subsequent appointment. In basic terms, this suggests that information created during an engagement will essentially be re-used and built upon in subsequent service providers. This one concept goes to the heart of digital engineering.

Project information shall be created using high quality processes, with consistent data structures and open formats, that are stored in linkable databases, so that it can be reliably accessed, trusted, consumed and re-used by subsequent downstream parties.

The value of all project information is retained (i.e. not lost), re-work / wasteful activities are avoided and the PIM continues to grow positively over the course of project delivery.

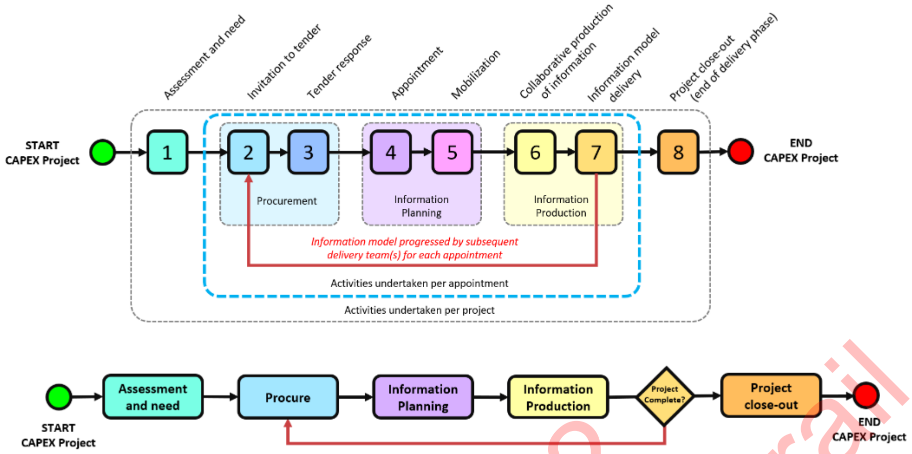


Figure 7.8: Information management process during the delivery phase of assets

This cycle of information of production and re-use occurs repeatedly over the course of project delivery as the project progresses through the CAPEX lifecycle, as represented in Figure 7.9. This diagram demonstrates how information management activities flow-on from one lifecycle stage to the next.

It also highlights once again the critical importance of ensuring data and information is produced and managed using tightly controlled processes, to ensure it can be re-used downstream to support subsequent activities over the full asset lifecycle.

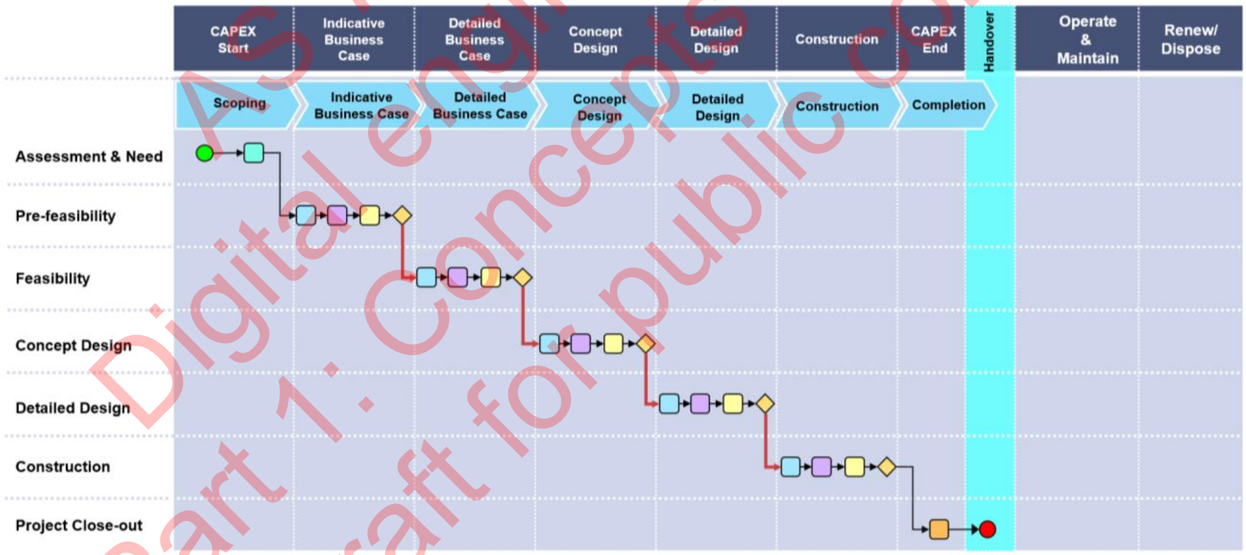


Figure 7.9: Iterative cycle of information management processes over project lifecycle

B.8 Legacy of ISO 19650 standards

ISO 19650 presents the opportunity for clients and industry to work together collaboratively under a common framework. Given the international status of these standards, they are now globally recognized and have become a catalyst for promoting the uptake of BIM and better information management on construction projects.

Clients now have a standardized method for expressing with information needs in the form of an EIR, and industry is now primed to review and respond to a client's EIR in the form of a BIM Management Plan. These standards have also kicked off a range of formal training courses, industry accreditation bodies and general enthusiasm for the bold future of the construction sector.

In Australia, the infrastructure and construction sectors are embracing these standards, with the commonly held view that these define global best practice for project and asset management. Over the past three years, the domestic construction sector has seen a rapid uptake in the use of these standards. Client agencies at all levels of government are now commonly prescribing guidance and project deliverables in accordance with ISO 19650. It is worth noting, references to ISO 19650 were even included in the recent Infrastructure Australia 2021 Australian Infrastructure Plan (released Sept 2021), which highlights the position in which these standards are held.

B.9 Limitations of ISO 19650

ISO 19650 has successfully begun to unify a fractured industry and is now bringing clients and industry together under a consistent set of processes. However ISO 19650 is currently limited in scope and is missing several components considered to be essential for successful digital transformation of the Australian rail infrastructure sector.

These limitations include:

(a) lack of technical detail;

(b) vague and unclear definition of BIM;

(c) lack of guidance on specific project deliverables;

(d) highly prescriptive and heavily administrative processes;

(e) outdated approach to information management, based on electronic file management;

(f) lack of definition on structured data;

(g) lack of advice on modern database management systems;

(h) overly simplistic asset lifecycle models;

(i) outdated terms and definitions.

The ISO 19650 suite of standards is a positive development for the buildings and civil infrastructure sector, that has raised the profile of information management for project delivery and asset management. That said, these standards are currently limited in their scope, with significant improvements necessary to define more efficient and appropriate data management solutions.

DE provides technical solutions to establish a digital ecosystem, that supports the overall digital asset lifecycle. Referring to Table 7.3 overpage, the DE equivalent of terms and definitions from the ISO are compared, to highlight the contrasting the level of technical specification between "IM according to the ISO 19650 series and DE.

If the rail industry is to progress and to truly become digital by default, further efforts are required to define more digital ways of working, and to build necessary capabilities such as data architecture, data modelling and design of database ecosystems.

Table 7.3: Comparison of ISO 19650 and AS 7739 - terms and definitions

BIM according to the ISO 19650 series		Digital Engineering
Terms	Definitions	Revised Terms and Definitions
BIM	Use of a shared digital representation of a built asset to facilitate design, construction and operation processes to form a reliable basis for decisions	Process of designing and constructing a building or infrastructure asset using object-based 3D modelling (i.e. 'smart 3D models')
Information container	Persistent set of information retrievable from within a file, system or application storage hierarchy	Specific actual deliverables with unambiguous data requirements (e.g. Docs, CAD, BIM, GIS etc)
Information model	Set of structured and unstructured information containers	Consistently structured datasets (i.e. dataset + metadata) managed as databases, with semantic interoperability
Common data environment	Agreed source of information for any given project or asset, for collecting, managing and disseminating each information container through a managed process	Digital ecosystem of linked databases, that hold consistently structured datasets
Information requirements	Specification for what, when, how and for whom information is to be produced	Data (& metadata) specifications (DS)
Organizational IR (OIR) Asset IR (AIR) & Project IR (PIR)	OIR = IR for organizational objectives AIR = IR for operation of an asset PIR = IR for delivery of an asset	Replace with ODS, ADS & PDS. Specify data & metadata (for org, AM and project) to ensure datasets can be federated for project activities, project reporting, program management, AM platforms, executive dashboards etc.
Exchange IR (EIR)	EIR = IR for an appointment	See above PDS
Appointing party	Receiver of information concerning works, goods or services from a lead appointed party (or delivery team)	Client
Appointed party	Provider of information concerning works, goods or services	Delivery partner
Trigger events	Planned or unplanned event that changes an asset or its status during its life cycle which results in information exchange	Lifecycle gates

Key decision point	Point in time during the life cycle when a decision crucial to the direction of viability of the asset is made	Lifecycle gates or sub-gates
Plain Language Question (PLQ)* *****(from BS 8536-2:2016, used to inform ISO 19650)	Request for information that is expressed in simple, easy-to-understand terms that are answered by the EIR	Database queries (e.g. Create, Retrieve, Update, Delete etc), required to inform business decisions. These queries are documented by the client, to determine metadata requirements for various actors, activities and lifecycle stages.

Appendix C Examples of Uniclass 2015 usage in projects

Informative

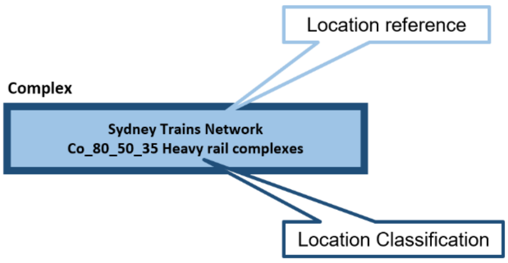
This section provides four additional examples of how Uniclass 2015 is applied in practice, including the following:

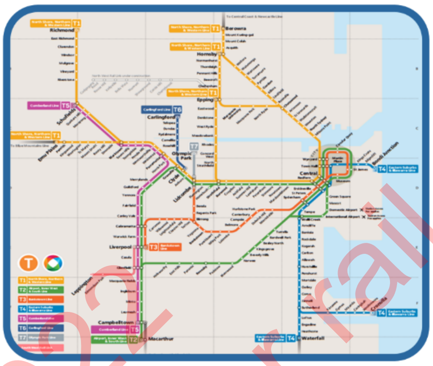
1. **Heavy Rail** – Track components
2. **Light Rail** – Station ticket vending machines
3. **Motorway** – Kerb and Pavement
4. **Building** – Internal fittings

C.1 Example 1: Heavy Rail – Track components

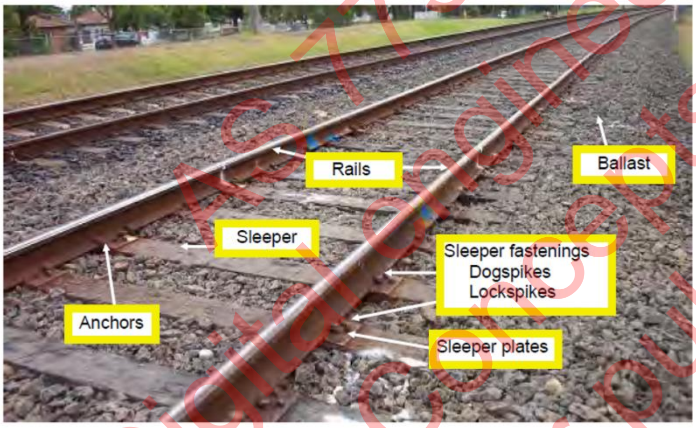
Location classification and referencing

The Sydney Trains Network is a **complex**.

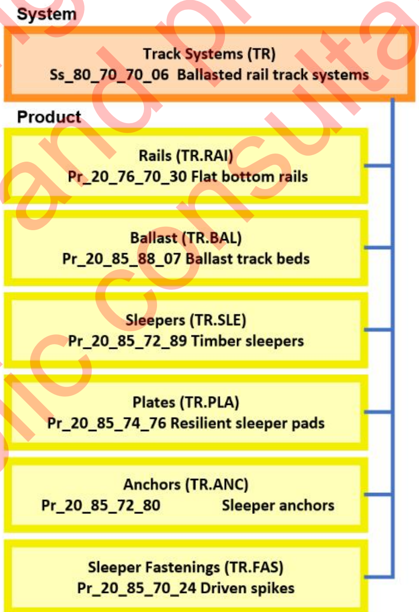




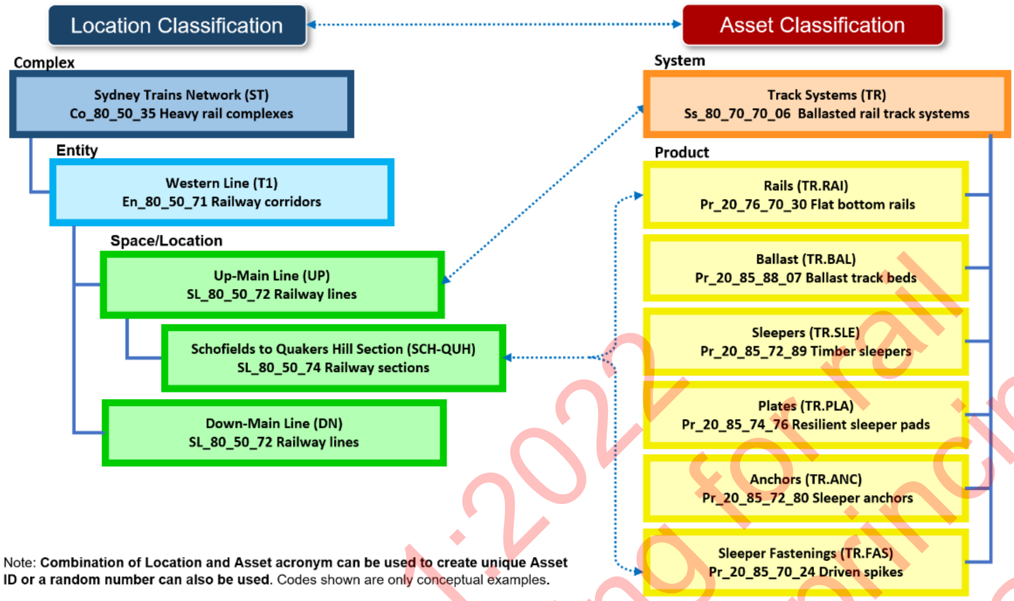
Asset breakdown



Source: Track fundamentals TMC 202 (Transport for NSW)



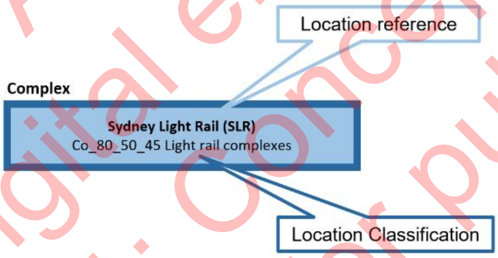
Associating assets to locations

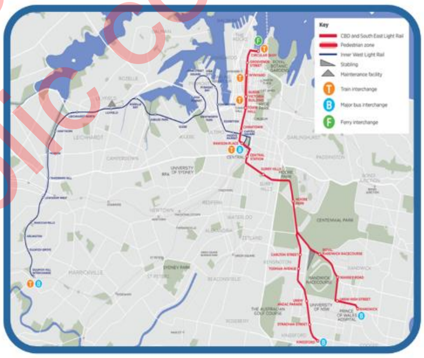


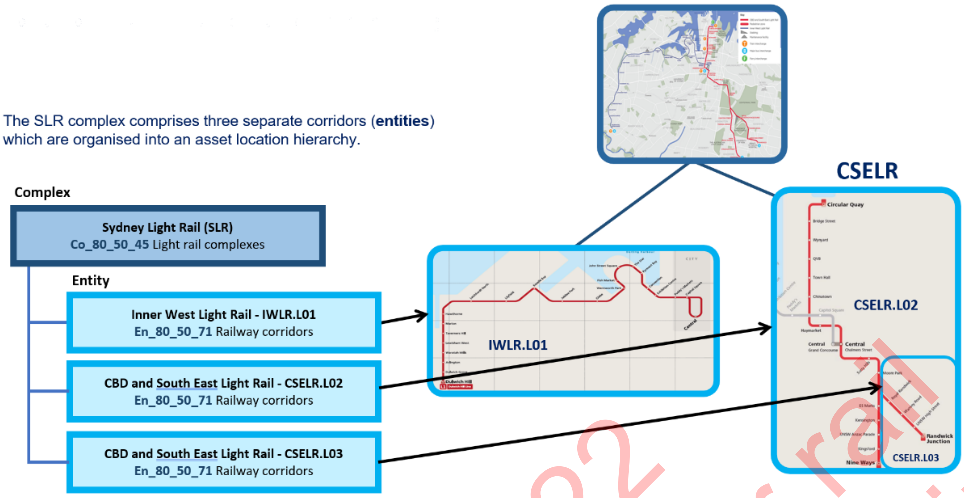
C.2 Example 2: Light Rail – Station ticket vending machines

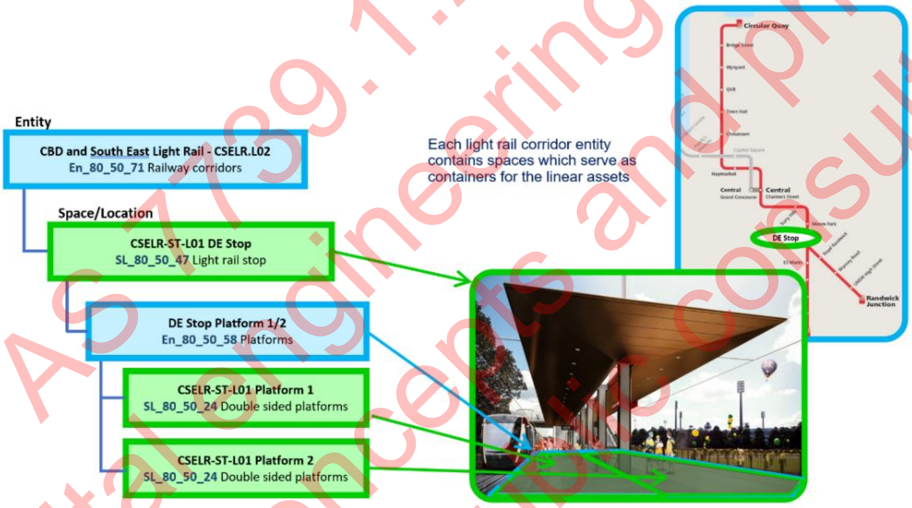
Location classification and referencing

The Sydney Light Rail (SLR) network is a **complex**.



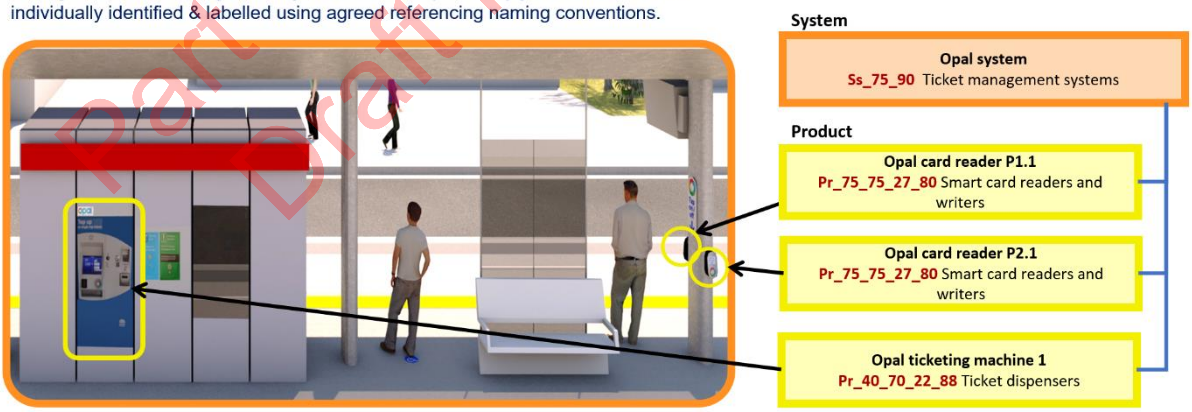




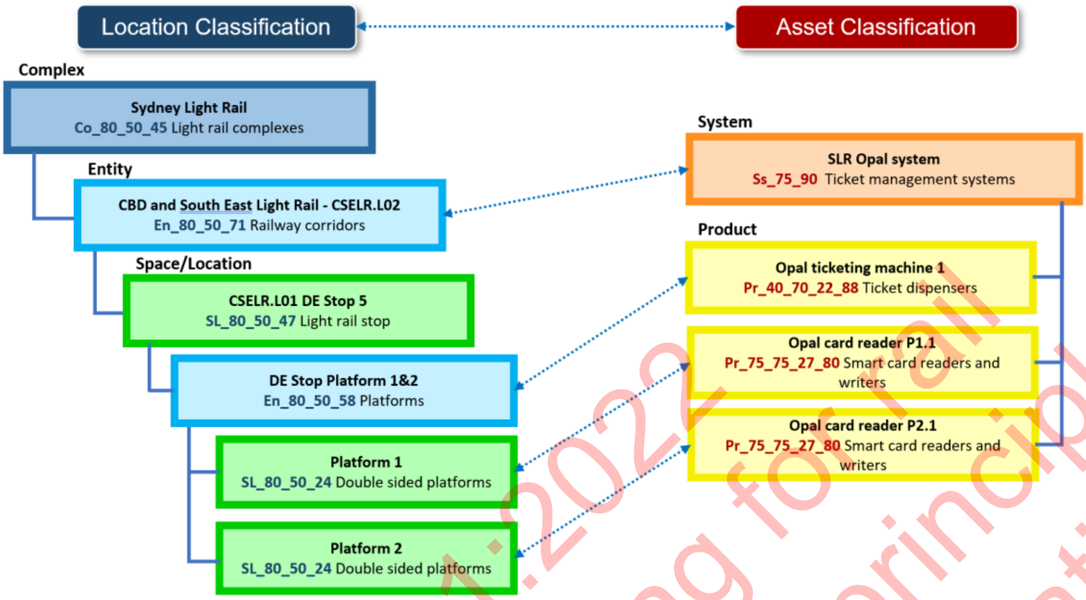


Asset classification and referencing

The light rail ticket management **system** is made up of many **products** which are individually identified & labelled using agreed referencing naming conventions.



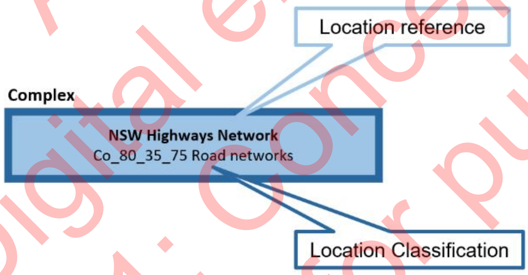
Associating assets to locations

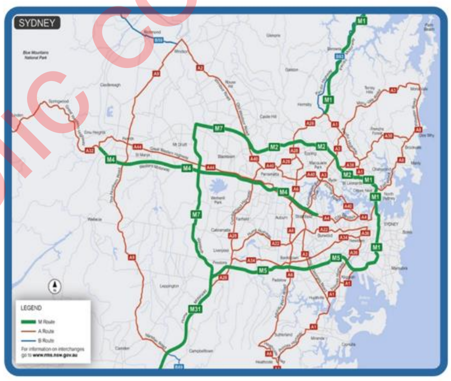


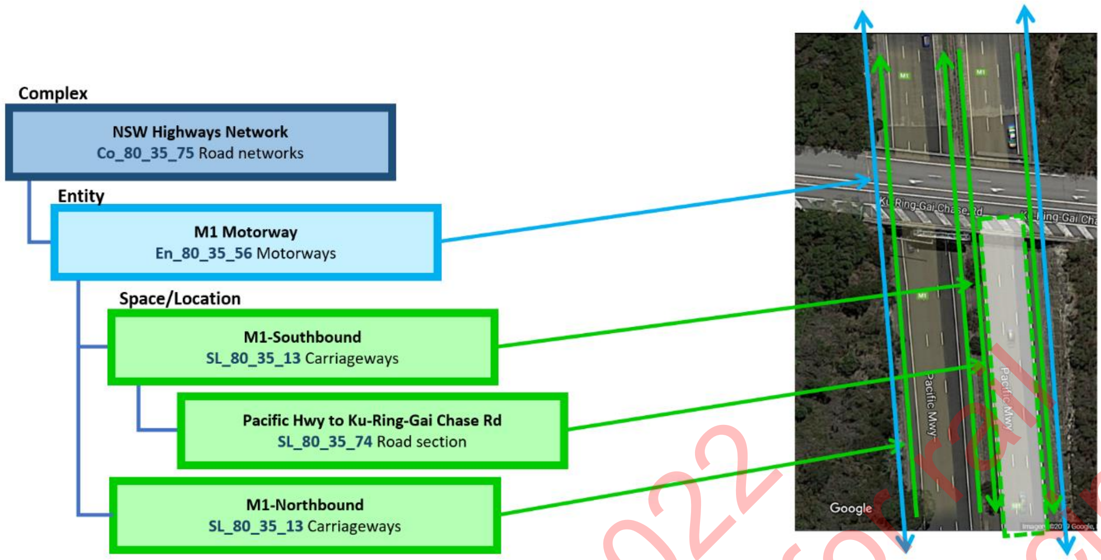
C.3 Example 3: Motorway – kerb and pavement

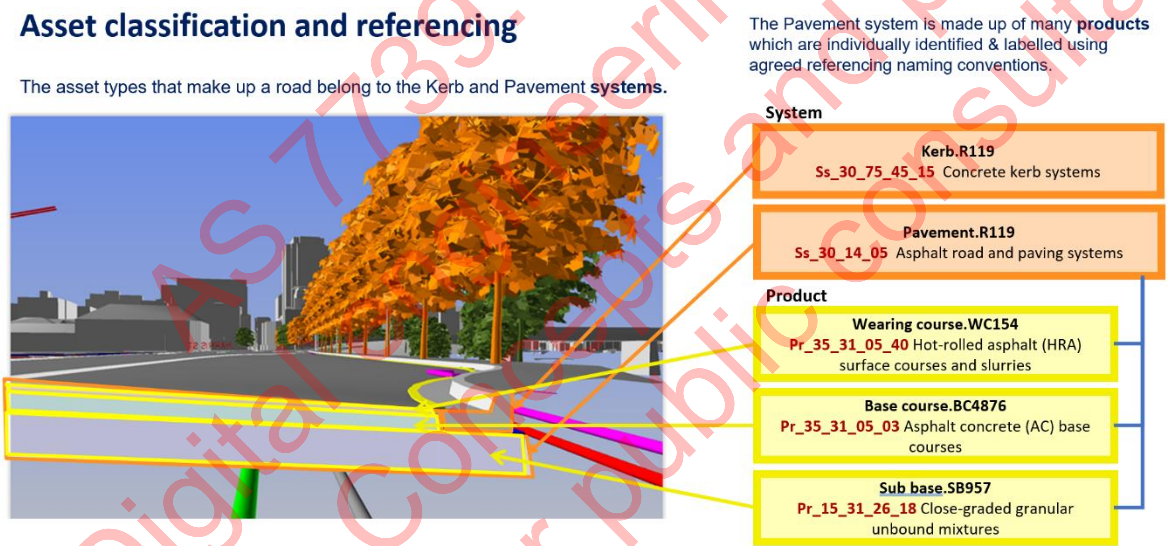
Location classification and referencing

The road networks are **complexes**.

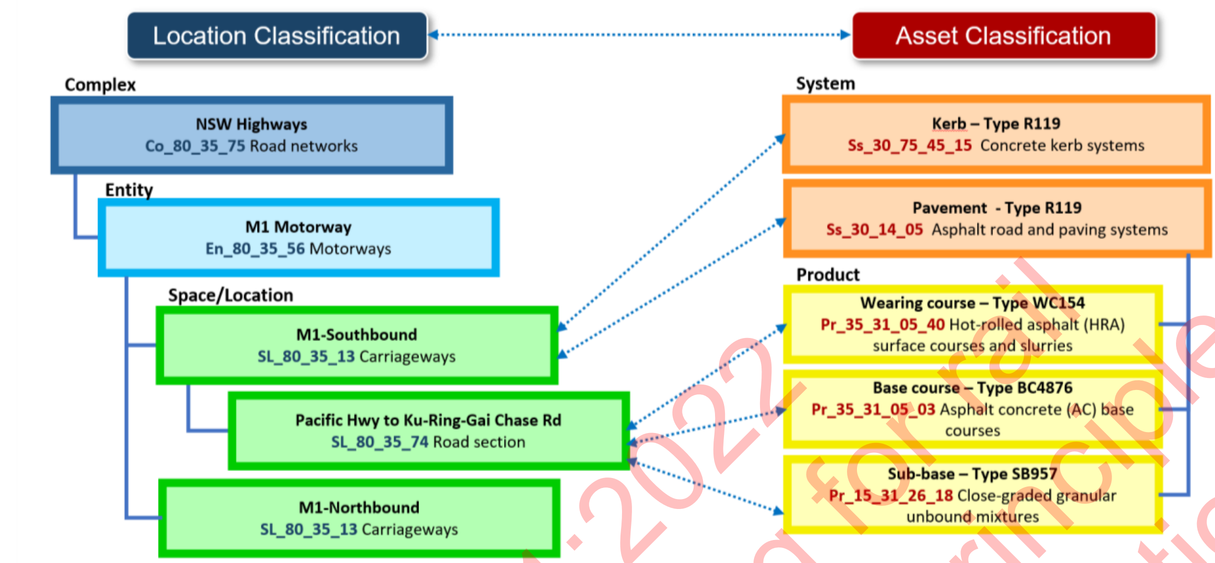




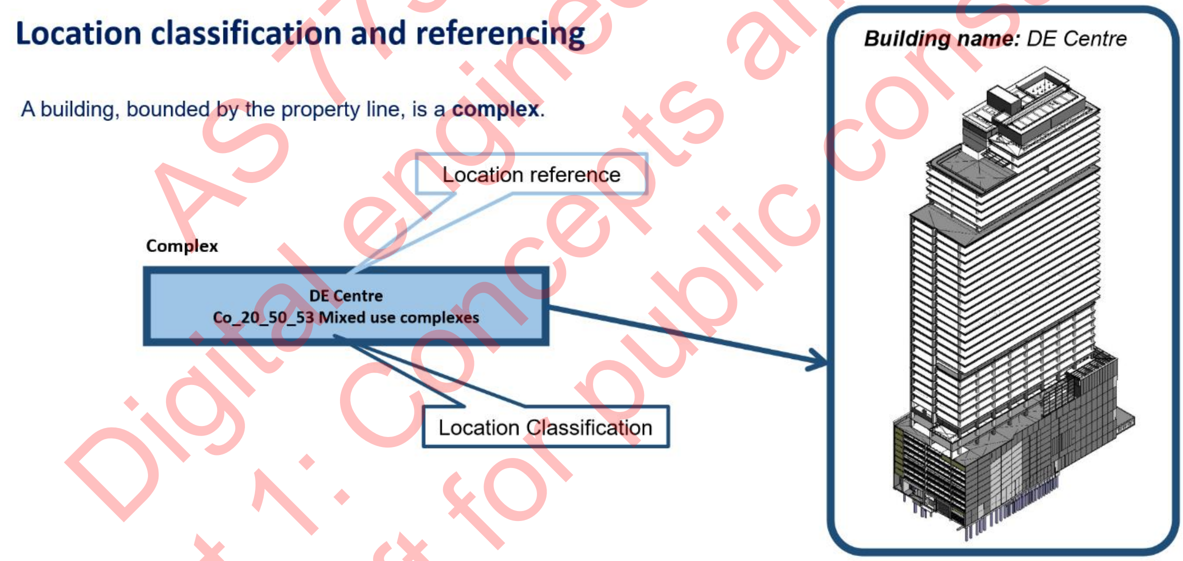

Complex
NSW Highways Network
Co_80_35_75 Road networks
Entity
M1 Motorway
En_80_35_56 Motorways
Space/Location
M1-Southbound
SL_80_35_13 Carriageways
Pacific Hwy to Ku-Ring-Gai Chase Rd
SL_80_35_74 Road section
M1-Northbound
SL_80_35_13 Carriageways
Pacific Hwy
Google

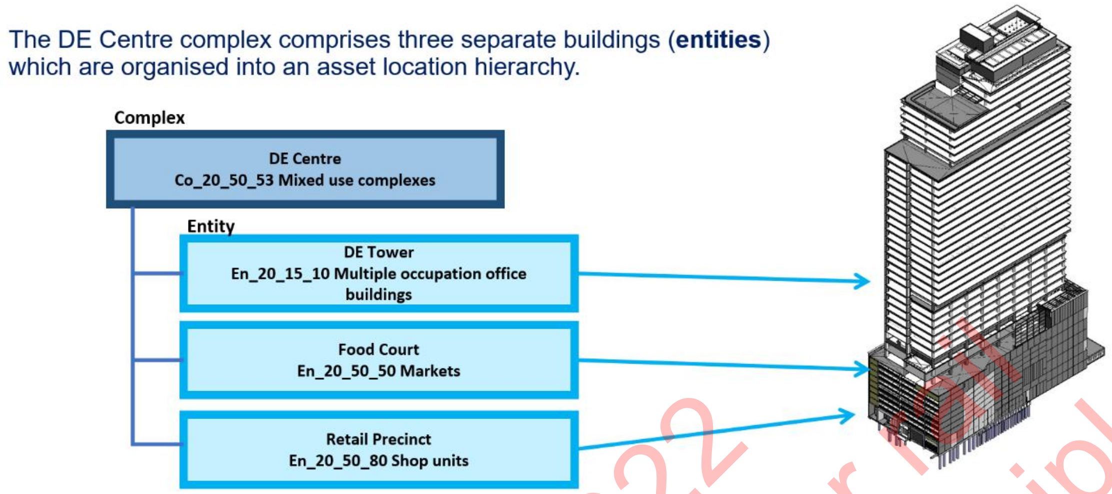

Asset classification and referencing
The asset types that make up a road belong to the Kerb and Pavement **systems.**
The Pavement system is made up of many **products** which are individually identified & labelled using agreed referencing naming conventions.
System
Kerb.R119
Ss_30_75_45_15 Concrete kerb systems
Pavement.R119
Ss_30_14_05 Asphalt road and paving systems
Product
Wearing course.WC154
Pr_35_31_05_40 Hot-rolled asphalt (HRA) surface courses and slurries
Base course.BC4876
Pr_35_31_05_03 Asphalt concrete (AC) base courses
Sub base.SB957
Pr_15_31_26_18 Close-graded granular unbound mixtures

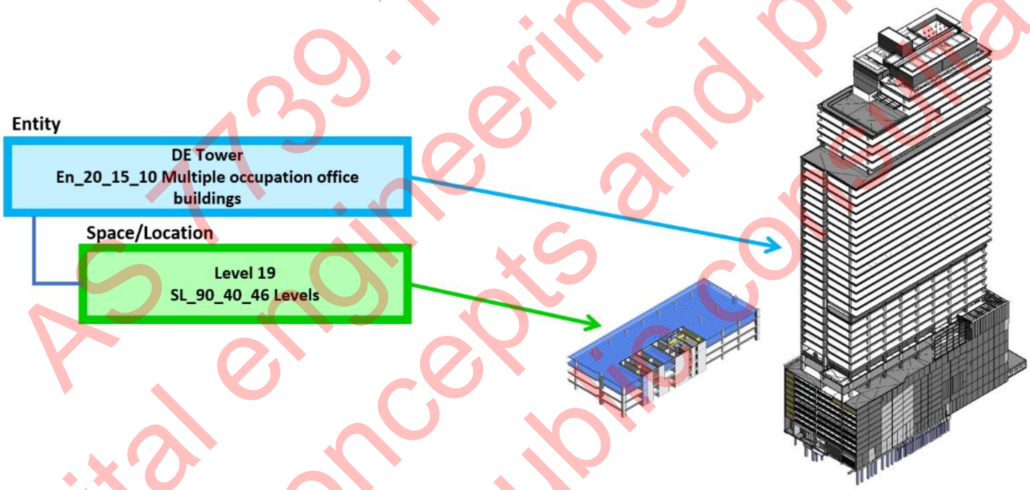
Associating assets to locations

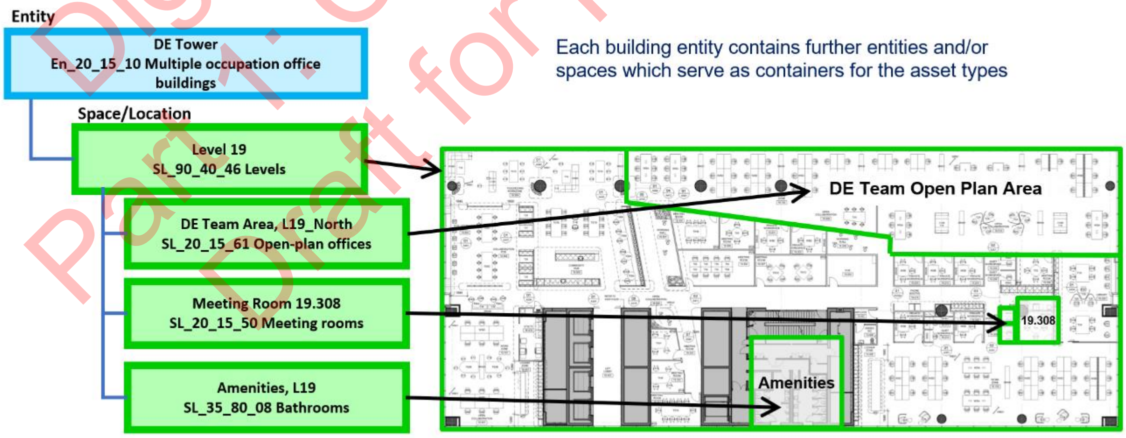


C.4 Example 4: Building – internal fittings




The DE Centre complex comprises three separate buildings (**entities**) which are organised into an asset location hierarchy.
Complex
DE Centre
Co_20_50_53 Mixed use complexes
Entity
DE Tower
En_20_15_10 Multiple occupation office buildings
Food Court
En_20_50_50 Markets
Retail Precinct
En_20_50_80 Shop units

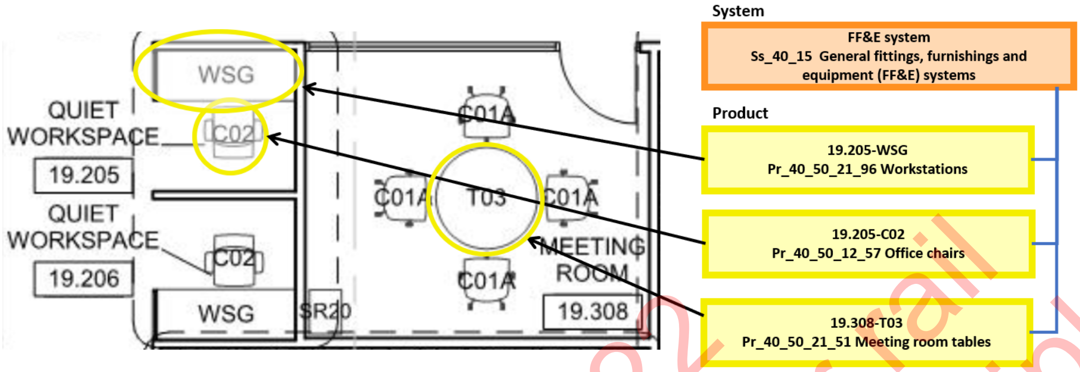

Entity
DE Tower
En_20_15_10 Multiple occupation office buildings
Space/Location
Level 19
SL_90_40_46 Levels


Entity
DE Tower
En_20_15_10 Multiple occupation office buildings
Space/Location
Level 19
SL_90_40_46 Levels
DE Team Area, L19_North
SL_20_15_61 Open-plan offices
Meeting Room 19.308
SL_20_15_50 Meeting rooms
Amenities, L19
SL_35_80_08 Bathrooms
Each building entity contains further entities and/or spaces which serve as containers for the asset types
DE Team Open Plan Area
19.308
Amenities

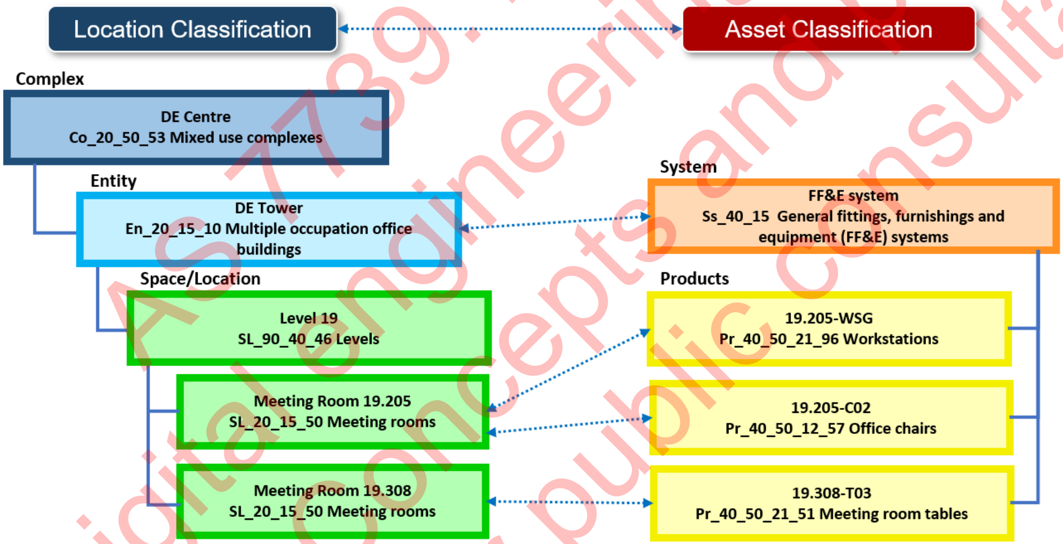
Asset classification and referencing

The asset types shown in the meeting rooms belong to the Furniture, fixtures and equipment (FF&E) **system**.

The FF&E system is made up of many **products** which are individually identified & labelled using agreed referencing naming conventions.



Associating asset to locations



Appendix D Bibliography

- ISO 19650 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) - Information management using BIM:
  - Part 1: Concepts and principles
  - Part 2: Delivery phase of the assets
  - Part 3: Operational phase of the assets
  - Part 4: Information exchange (Draft)
  - Part 5: Security-minded approach to information management
- ISO 12006.2 - Building construction - Organization of information about construction works - Part 2: Framework for classification
- Guide to the Data Management Body of Knowledge (DAMA International, 2nd Edition 2017)
- Intergovernmental agreement on data sharing between Commonwealth and State and Territory governments (National Cabinet, 2021)
- National digital engineering policy principles (Australian Department of Infrastructure, Transport, Regional Development and Communications, 2017)

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Once agreed by the Development Groups, Standing Committees and Validator, the drafts are passed to the RISSB Board for approval.

The same process is used in developing other RISSB products, although Guidelines are not exposed to the public for comment or validated, given their non-binding nature.

Standards Development and Accreditation Committee

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