Digital Asset Information Management (DAIM): *Case Studies*

Final Case Studies Report, Project 2.51

Developing a Cross-sector Digital Asset Information Model Framework for Asset Management

December 2018

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Sustainable Built Environment National Research Centre

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SBEnrc Project Partners and Affiliates who participated in the case studies include VicRoads, Transport for New South Wales, Public Transport Authority Western Australia, the Facility Management Association of Australia, The Australian Road Research Board, Fulton Hogan and Advanced Spatial Technologies.

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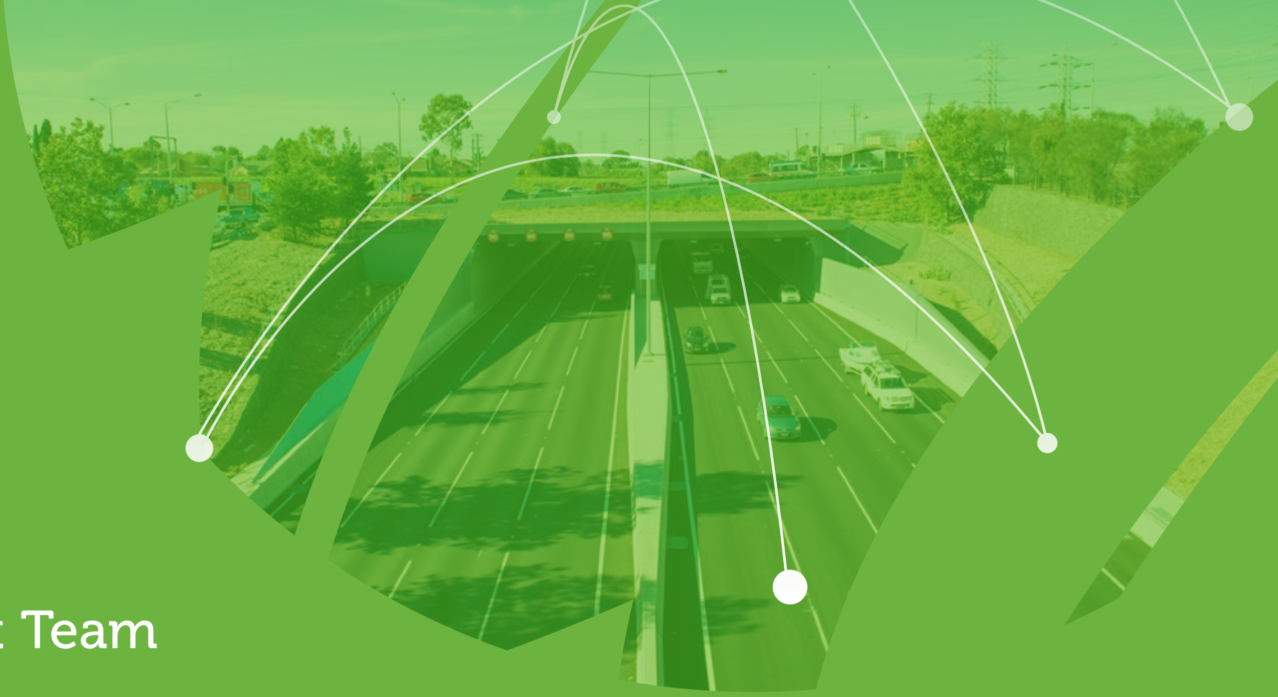

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Preface

The Sustainable Built Environment National Research Centre (SBEnrc), the successor to Australia's Cooperative Research Centre (CRC) for Construction Innovation, is committed to making a leading contribution to innovation across the Australian built environment industry. We are dedicated to working collaboratively with industry and government to develop and apply practical research outcomes that improve industry practice and enhance our nation's competitiveness.

We encourage you to draw on the results of this applied research to deliver tangible outcomes for your operations. By working together, we can transform our industry and communities through enhanced and sustainable business processes, environmental performance and productivity.

John V McCarthy AO
Chair

Sustainable Built Environment
National Research Centre

Dr Keith Hampson
Chief Executive Officer

Sustainable Built Environment
National Research Centre

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Executive Summary

Building Information Modelling (BIM), as an intelligent 3D model-based process to inform and communicate project decisions, has received much attention in the design and construction stage of construction projects. In order to promote BIM and other digital engineering technologies for more effective use in informed asset management decisions, the Sustainable Built Environment National Research Centre (SBEnrc) Project 2.51 focused on a comprehensive review of digital asset management practices, including asset data exchange, asset classification, asset location referencing and asset information requirements.

This *Digital Asset Information Management: Case Studies* is one of three documents produced by SBEnrc Project 2.51 *Developing a Cross Sector Digital Asset Information Model Framework for Asset Management.*[1] The three documents are complementary:

1. Digital Asset Information Management: Research Report
2. Digital Asset Information Management (DAIM): A Guide and Manual
3. Digital Asset Information Management: Case Studies (this document)

This *Case Studies* report uses current exemplar projects to examine asset management processes across the project's collaborating industry partner organisations across Australia. These projects were selected against a number of criteria:

1. Coverage of asset types: housing, non-residential buildings and transport infrastructure;
2. Levels of engagement with BIM, from current industry practice to leading edge BIM application;
3. Geographical coverage across Australia.

The case studies themselves were used to pinpoint issues in identifying the information needed to understand the use of BIM for asset management, ways of improving the use of BIM-based technology to support asset management and the changes needed for industry processes to make this more efficient.

The *housing* case studies illustrate:

1. The current approach, where data must be extracted manually from the specifications and 2D drawings (Elger Street Social Housing);
2. The use of BIM for design and construction, but the additional modifications needed to support asset management (Jellicoe Street Social Housing);
3. The need to extend existing asset management systems to support the new Australian National Disability Insurance Scheme (NDIS) scheme (WA Department of Communities).

The *building* case studies illustrate:

1. The uptake strategies across a portfolio of buildings to gradually upgrade existing systems and processes to incorporate BIM (Curtin University, Bentley Campus, Perth, Building 109);
2. The integration of BIM into an asset management system to more fully exploit the richness of BIM data (Warren Districts Hospital and James Cook University Biotechnology Building).

The suite of housing and building case studies demonstrates that the use of BIM can improve asset management process by (i) improving the capture of asset management data by supporting the selection of relevant objects and attributes; (ii) supporting direct import to the selected objects and attributes; and

[1] SBEnrc Project 2.51: https://sbenrc.com.au/research-programs/2-51/

(iii) improving the ability to examine assets within their context through support for 3D viewing. The introduction of the NDIS scheme in Australia to support social housing needs (amongst other goals) is a reminder that asset management systems need to support change, as data analysis and retrieval needs change over time. The Elger Street housing project indicates that the level of effort put into BIM modelling needs to be balanced against the ease with which the asset data can be imported into an asset management system. In some circumstances, it may be more efficient adding some data directly, after importing the available BIM data through a COBie[2]-like process.

The *transport infrastructure* case studies illustrate:

1. An example of applying BIM for road asset lifecycle management which includes development of the Road Asset Information Requirement, Road Asset Classification System and Road Location Referencing System that is specific to this case (Armadale Road Upgrade);
2. An approach of developing detailed rail asset information templates to guide the asset information creation and updating during project design, construction and handover stages (Forrestfield Airport Link);
3. The application of BIM for bridge design and construction optimisation, and how to continually use the as-built 3D Bridge Information Model to support bridge operation and maintenance (New Grafton Bridge);
4. An example of applying Digital Asset Information Management to facilitate digital transformation at an enterprise level (DAIM in VicRoads).

The transport infrastructure case studies demonstrate that the use of BIM together with the proposed DAIM can significantly improve asset lifecycle management processes by (i) standardising asset data capturing processes; (ii) streamlining asset information flows from project design to handover stage; and (iii) automating asset data transformation from one system to another. The Armadale Road Upgrade project indicates that investigating existing road asset management systems is key to the success of digital asset information management. The Forrestfield Airport Link project shows the value of the client's asset management team taking the lead in developing asset information requirements and asset information delivery processes. The New Grafton Bridge case study highlights the importance of defining asset information requirements at the earliest stage in a project. At an organisational level, large companies are well advised to develop their own digital transformation strategies to facilitate digital asset information management.

[2] COBie: Construction Operations Building information exchange

1. Housing Case Studies

The three case studies for the housing sector represent different digital asset management scenarios. Approximate locations of case studies are shown in Figure 1.

Case Study 1 – the Jellicoe Street project is an example of a full BIM (Building Information Modelling) project which was completed before the completion of the COBie (Construction Operations Building information exchange) development project (East, 2016). The BIM for this project was also created to support the design/construction process, with little thought for how the data could then be re-used to support asset management. While the original BIM for Jellicoe Street did not provide good results using COBie tools, minor modifications to the relevant objects within the BIM enabled good useable data to be extracted with the COBie tools. This demonstrates that good BIM models can produce useful results beyond the intentions of the original BIM creators.

Case Study 2 – the Elger Street project is an example of a common scenario within current industry practice. The documentation may have been produced in either 2D or 3D software, but the documents are then only distributed as PDFs with the project specification. The specification gives most of the attribute information necessary for asset management. The necessary geometrical and topological information is in the PDF documents. Extraction of the asset management information is time consuming and tedious. Access to the originating electronic models would have significantly simplified the data extraction task.

Case Study 3 – information from the Western Australia Department of Communities (Housing division) demonstrates how meta-data from an Australian Government-funded program (the National Disability Insurance Scheme – NDIS) provides definitions necessary to determine the degree of customisation provided to a property to meet the needs of a person with a disability. Various design criteria need to be satisfied for the dwelling to be accredited under the requirements of the Australian Government program.

Figure 1: Approximate Locations of Housing Case Studies

1.1 Housing Case Study 1: Jellicoe Street, Toowoomba (QLD)

1.1.1 Project overview

This multi-residential housing project consists of ten two-bedroom apartments arranged in two-storey building blocks located at Jellicoe Street in Toowoomba (Figure 2), west of Brisbane, Queensland. Construction was completed in December 2012 and the tender amount for this project was approximately A$2.5 million.

Figure 2: Jellicoe Street Housing

The Jellicoe Street project was designed and documented by the Project Services Group within the Queensland Department of Public Works (now the Department of Housing and Public Works). The Toowoomba City Council was a major stakeholder for this project, being particularly interested in the removal of overland water flow from the site.

Project Services was leading the architectural industry in Queensland in the use of BIM programs such as Revit and ArchiCAD to produce 3D building models at the time the project was designed and constructed. The Jellicoe Street project was modelled using Revit Architecture, Revit Structure and Revit MEP[3]. Additionally, Solibri model checker[4] was used for clash detection.

BIM models for this project include:

- A site model including the carport shelters, bin shelters, utility buildings, all concrete paving, retaining walls etc. (Figure 3). Site retaining wall footings were not modelled but were captured in the Bill of Quantities.
- Structural models, including the piers required on the low-lying and swampy site (Figure 4).
- Fully modelled hydraulic services - stormwater, house drainage, hot and cold water, tank water).
- Electrical site and building models.
- Existing and new topography.
- Bill of Quantities based on the BIM model and associated 2D Drawings.
- A CostX[5] template file.

Figure 3: Jellicoe Street Site Model

[3] REVIT: https://www.autodesk.com.au/collections/architecture-engineering-construction/building-design
[4] Solibri: https://www.solibri.com
[5] CostX: https://www.exactal.com/

The Department provided specialised training in using Navisworks[6] as viewing software for contractors who were interested in using BIM.

This project was used by this leading Queensland Government procurement unit as part of the BIM standards establishment and continuity of use of BIM models by tenderers and contractors. Since multi-residential housing projects generally require fewer disciplines than larger projects, this helped to establish a collaborative approach to producing a model without the wider complexities of a full consultant team.

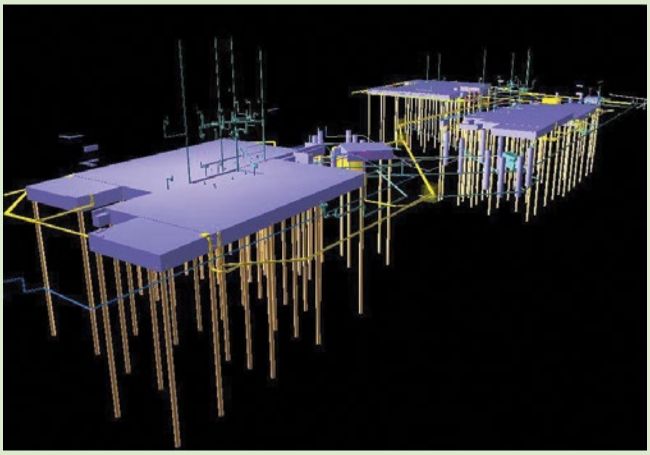


Figure 4: Jellicoe Street Structural Model Piers to Slabs

In responding to tenderers' comments from previous projects, Project Services modelled a wide range of content in the Jellicoe Street project. These improvements consisted of a full site model including topography and other features, the complete hydraulics works including all in-ground services, and a full structural model including roof framing.

1.1.2 Tenderers and outcomes at tender

The tenderers were required to use the BIM model to help prepare the Tender Submission with the understanding that the tenderer who won the project would be required to continue using the BIM model to help clarify construction issues and identify advantages/limitations in the approach used at the time by the client. A post-tender review specifically dealing with BIM and modelling issues was conducted with the three participating tenderers. The review outcomes were:

- Generally, the model was useful in preparing the tender;
- All tenderers provided positive feedback regarding viewing the facility model, walking through the model, and looking at various cross sections etc. This provided an improved understanding of the project and its components;
- The review of the model with all tenderers and follow up training using Navisworks was successful. This building of industry capacity for future application was noted and appreciated.
- Virtual models of the project site and adjacent sites were useful in providing a visual context for the site and informed planning of access to the site;
- The availability of the Navisworks Viewer as free software encouraged its use by the site personnel;
- Navisworks supports the selective display of information in the model, leading to an improved understanding of the building systems and of the inter-relationships between them;
- The direct compatibility of Navisworks with Revit provided simple exchange of the model files.

[6] Navisworks: https://www.autodesk.com.au/collections/architecture-engineering-construction/overview

1.1.3 Outcomes during construction

A key goal for Project Services of moving into the 'virtual model' world was to reduce construction issues requiring the raising of Requests for Information (RFIs) which take time to answer and often result in variations to the contract. Discussions with Project Services staff and the tendering contractors showed that the model was used during the tender process to identify possible difficulties that may arise in the construction phase. A number of RFIs included reference to the BIM model and identified where the Contractor could not obtain the necessary information from the model.

A review by Project Services with the successful contractor's staff indicated that the BIM model had a positive impact on the construction site. Firstly, the contractor received the normal construction documents in addition to a Bill of Quantity (BOQ) – produced from the model – which was an additional document not generally included in a project of this size.

The number of RFIs for this project could be considered a little more than normal. However, most of these RFIs were related to civil works. The project was commenced immediately after a sustained period of wet weather and significant flooding. The contractor raised many issues regarding the bearing capacity of the soil, imported fill and the design of the retaining walls, paving slabs and external works. Additionally, a number of these civil issues were concerning the driven timber piles and the impact on neighbouring properties.

The 'virtual model' did contain some design information available from the structural Revit model; however, this could never have resolved the above-mentioned site civil issues.

Some of the RFIs were in relation to operational works where the stormwater drainage on the one end of the site was required to be discharged through an easement to the adjacent creek.

1.1.4 Conclusions

The importance of this project as a case study in this research lies in the comprehensive BIM model that was produced to support construction documentation. It shows that a comprehensive BIM model is feasible and even desirable on smaller projects. The feasibility of bringing the model directly into an asset management system was tested using the COBie[7] export utility for the Autodesk Revit software. The original naming conventions and attribute policies within the BIM model did not conform to the COBie standard. However, minor editing of the relevant families (object definitions) within Revit led to successful export of valid COBie files. These could then be imported directly into a COBie-conformant asset management system.

[7] COBie: Construction Operations Building information exchange

1.2 Housing Case Study 2: Elger Street Housing, Glebe (Sydney, NSW)

1.2.1 Project overview

The Elger Street project (Figure 5) is a social housing project located in the Sydney suburb of Glebe. It is managed by the Land and Housing Corporation within the NSW Department of Family and Community Services. It is a group of multi-storey residential buildings developed on two sites across the road from each other, in which each block consists of a number of one- and two-bedroom units.

Figure 5: Elger Street Social Housing Project[8]

This development is important within the context of these digital asset information case studies for two reasons. Firstly, it provides a base case of current practice against which the other case studies can be assessed. Secondly, as a residential building with services, it provides an intermediate example between non-serviced residential accommodation and larger, fully serviced, non-residential buildings.

This case study concentrates on the services within the development as these are the systems within buildings which require the most management from an asset management perspective. It should be noted that all of the other industry organisations involved in SBEnrc Project 2.51 will have assets which were documented in a similar manner to this development.

The services documentation for this development consists of electrical and mechanical drawings (examples in Figure 6 and Figure 7), in addition to hydraulic drawings and hydraulics, and mechanical and electrical specifications. This documentation can be used to manually extract information for asset management purposes. The data related to each individual component can be found in the specifications documents, while the pdf drawings provide a schematic of the component locations. A manual inspection of the development is normally required to ensure that the documentation accurately represents as-built.

Both drawings and specifications are necessary to identify the systems and individual components that are part of that system. For example, to identify which air-conditioning duct belongs to which unit.

[8] Source: http://www.kane.com.au/project/glebe-social-housing

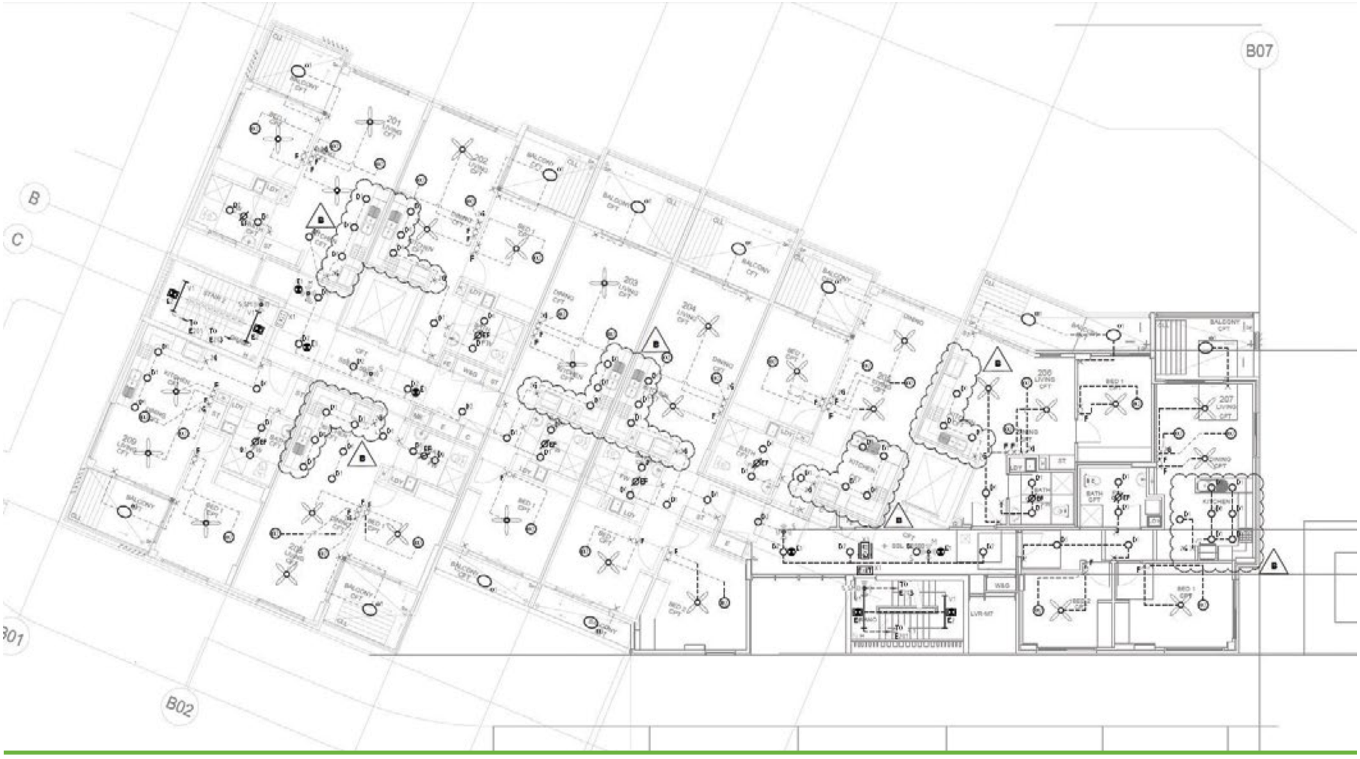


Figure 6: Elger Street Partial Electrical Plan

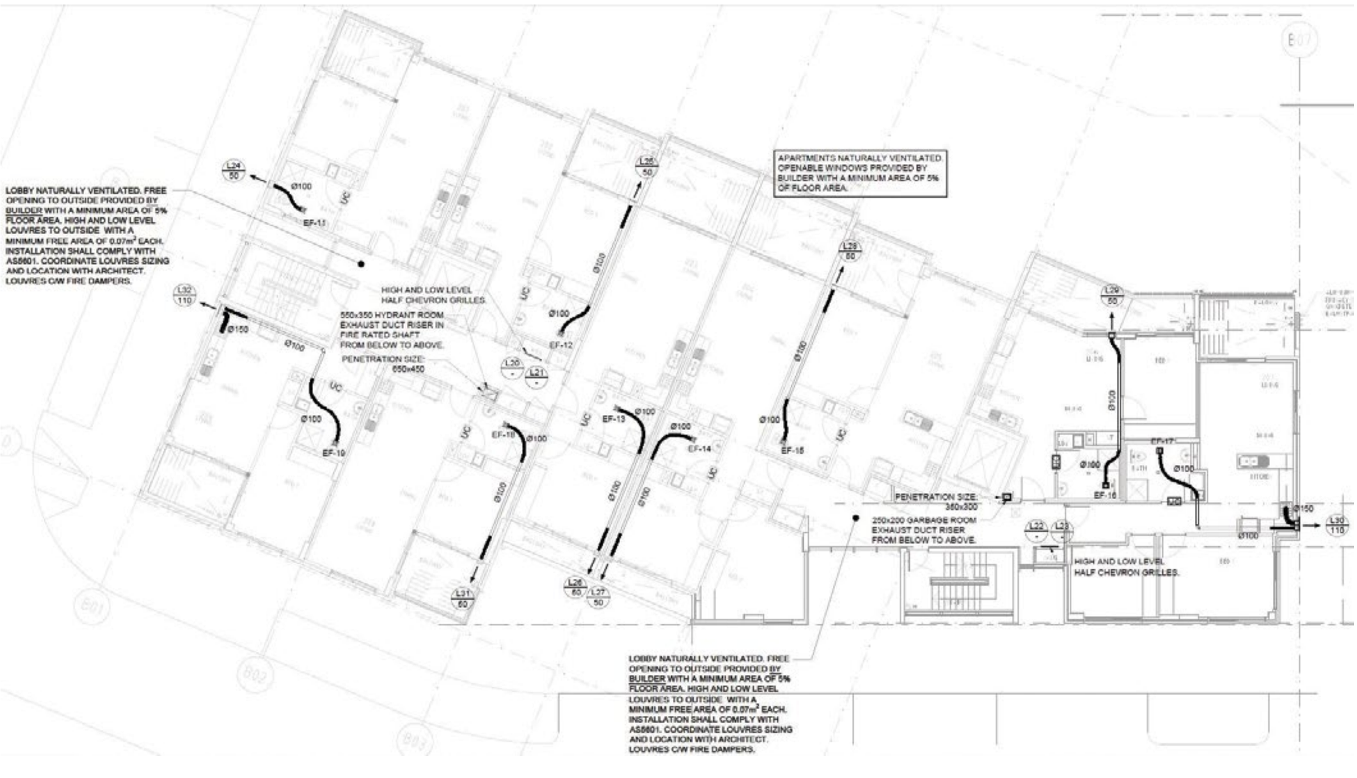


Figure 7: Elger Street Partial Mechanical Services Plan

Using 'non-intelligent' media to document the development presents several issues:

1. It is difficult to coordinate between different systems within the building. For example, since electrical and mechanical services are documented on different sheets for the same location it can be difficult to determine which electrical connections supply power to specific items of mechanical plant;
2. The need to use legends and symbols (Figure 8) to represent the systems and components can be prone to error, especially when working through hundreds of sheets of drawings. 'Intelligent' media, such as BIM, allows a user to select an object within an electronic version of the model to see what type of object it is and its characteristics. The ability to move around in a BIM model also assists in comprehension of the development itself and all of its constituent systems and components;
3. Current practice for this type of project within the industry as a whole is for the major building components to be modelled in BIM, with the services schematics being documented in 2D over drawings generated from the BIM model. The BIM model and the 2D schematics can be queried to generate object counts to assist in building the asset management data. This can also apply to other projects documented entirely in 2D if the original electronic documents are available.
4. It is normally more difficult to extract information for projects that were documented before CAD or BIM usage became common, as the documentation will often consist of pdfs generated by scanning the original paper-based drawings. All of the items from the documentation will then have to be counted manually. This can be a significant source of errors.

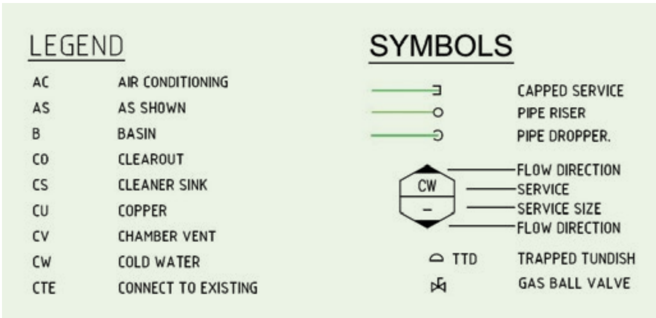


Figure 8: Elger Street Partial Mechanical Services Legend and Symbols

1.2.2 Conclusions

The documentation for this project, using BIM for the major architectural and structural elements to generate the plans, elevations and sections, and 2D to generate overlays of details and schematics, is typical of common industry practice in Australia at this time. It demonstrates that the full use of BIM is not necessary for simpler building types. The ability to generate object/block counts from 2D schematics, with appropriate duplicate checking, can be appropriate for adding data to the asset management system.

1.3 Housing Case Study 3: Disability Accommodation and the National Disability Insurance Scheme (WA)

1.3.1 Project overview

The Western Australian (WA) Department of Communities[9] is responsible for managing over 36,000 public housing dwellings for people on low incomes and 2,662 properties for 114 Aboriginal communities in remote locations. It is the largest housing landlord in Western Australia.

The National Disability Insurance Scheme (NDIS) is an Australian Government initiative that will provide Specialist Disability Accommodation (SDA) payments to an estimated 6 percent of NDIS participants (28,000 people nationally) managed through the Australian National Disability Insurance Agency (NDIA). These payments will be dependent on the specialist features required by the participant in the dwelling.

The NDIS SDA Price Guide 2017-18 sets out these design categories, as below in Table 1. An ability to demonstrate compliance with each category will be required to claim SDA payments from the NDIA, when an eligible participant is living at the property. This payment mechanism is important to the financial sustainability of existing disability housing programs and essential to facilitating the development of new dwellings, allowing participants to have increased choice and control over where they reside. The WA Department of Communities recognises the need to record more detailed information about these special purpose dwellings to enable better matching to clients' needs and easier identification of the NDIS support categories and associated funding available.

Table 1: NDIS SDA Price Guide 2017-2018

SDA Design Category	Definition	Minimum Requirements
Basic	Housing without specialist design features but with a location or other features that cater for the needs of people with disability and assist with the delivery of support services	The Basic design category only applies for Existing Stock or Legacy Stock (SDA Rules 6.10(c)) and cannot be included in a participant's plan except as an alternative interim option or if the participant already lives in Basic design SDA (SDA Rules 4.4 and 4.11)
Improved Liveability	Housing that has been designed to improve 'liveability' by incorporating a reasonable level of physical access and enhanced provision for people with sensory, intellectual or cognitive impairment	• Liveable Housing Australia 'Silver' level • The designed environment responds to the needs of participants through improved physical access and enhanced provision for participants with sensory, intellectual or cognitive impairment. For example Improved Liveability dwellings should include one or more additional design features such as luminance contrasts, improved wayfinding and/or lines of sight depending on the needs of the participants

[9] WA Department of Communities: https://www.communities.wa.gov.au/services/housing/

Table 1: NDIS SDA Price Guide 2017-2018 (continued)

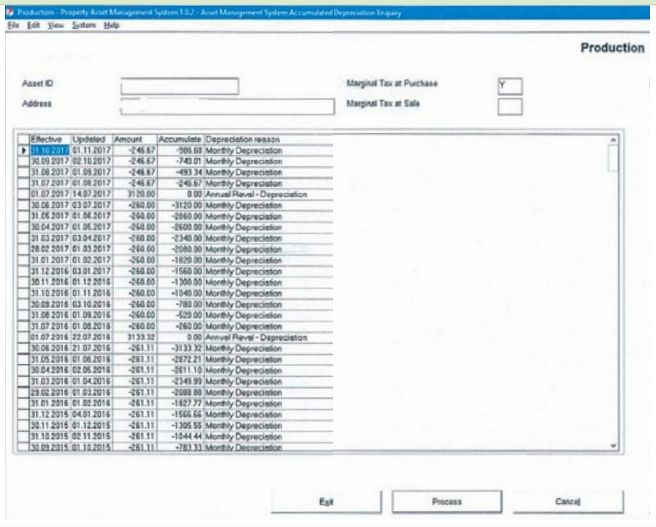
SDA Design Category	Definition	Minimum Requirements
Fully Acessible	Housing that has been designed to incorporate a high level of physical access provision for people with significant physical impairment	• Liveable Housing Australia 'Platinum' level • External doors and external outdoor private areas to be accessible by wheelchair • Bathroom vanity/hand basin to be accessible in seated or standing position • Power supply to doors and windows (blinds), for retrofit of automation as necessary • Consideration must be given to whether it is appropriate for the kitchen sink, cooktop, meal preparation bench area and key appliances (dishwasher, oven, microwave oven, laundry appliances) to be accessible in seated or standing position
Robust	Housing that has been designed to incorporate a high level of physical access provision and be very resilient, reducing the likelihood of reactive maintenance and reducing the risk to the participant and the community.	• Liveable Housing Australia 'Silver' level • Resilient but inconspicuous materials that can withstand heavy use and minimises the risk of injury and neighbourhood disturbance including: - high impact wall lining, fittings and fixtures (e.g. blinds, door handles) - secure windows, doors and external areas - appropriate sound proofing if residents are likely to cause significant noise disturbances (if required must retrofit in new builds if not previously installed at building stage) - laminated glass • Layout with areas of egress and retreat for staff and other residents to avoid harm if required • Consideration must be given to providing adequate space and safeguards throughout the property to accommodate the needs of residents with complex behaviours

Table 1: NDIS SDA Price Guide 2017-2018 (continued)

SDA Design Category	Definition	Minimum Requirements
High Physical Support	Housing that has been designed to incorporate a high level of physical access provision for people with significant physical impairment and requiring very high levels of support	• Liveable Housing Australia 'Platinum' level • External doors and external outdoor private areas to be accessible by wheelchair • Bathroom vanity/hand basin to be accessible in seated or standing position • Power supply to doors and windows (blinds), for retrofit of automation as necessary • Consideration must be given to whether it is appropriate for the kitchen sink, cooktop, meal preparation bench area and key appliances (dishwasher, oven, microwave oven, laundry appliances) to be accessible in seated or standing position • Structural provision for ceiling hoists • Assistive technology ready • Heating/cooling and household communication technology (e.g. video or intercom systems) appropriate for the needs of residents • Emergency power solutions to cater for a minimum two hour outage where the welfare of participants is at risk • 950mm minimum clear opening width doors to all habitable rooms

The WA Department of Communities uses multiple systems for processing, budgeting, management and other activities associated with its assets. For example, the Property Asset Management System (PAMS) can present financial information, such as valuations and capital cost in simple tabular screens (Figure 9), and individual repair requests are entered on a standard form in the tenancy management system HABITAT (Figure 10).

This system currently used by WA Department of Communities is a typical 'data-driven' asset management system of the type that currently dominates built environment asset management. This can pose constraints, such as a limited capacity for predictive maintenance and the ability to handle complex and mixed-use construction projects. Adjustments to properties such as lowering the height of light switches, for example, may be entered as a repair rather than a change request. This can make tracking improvements or modifications more difficult.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File Edit View System Help

Production

Asset ID

Address

Marginal Tax at Purchase Y

Marginal Tax at Sale

Effective	Updated	Amount	Accumulate	Depreciation reason
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30.09.2017	02.10.2017	-246.67	-740.01	Monthly Depreciation
31.08.2017	01.09.2017	-246.67	-493.34	Monthly Depreciation
31.07.2017	01.08.2017	-246.67	-246.67	Monthly Depreciation
01.07.2017	14.07.2017	3120.00	0.00	Annual Reval - Depreciation
30.06.2017	03.07.2017	-260.00	-3120.00	Monthly Depreciation
31.05.2017	01.06.2017	-260.00	-2860.00	Monthly Depreciation
30.04.2017	01.05.2017	-260.00	-2600.00	Monthly Depreciation
31.03.2017	03.04.2017	-260.00	-2340.00	Monthly Depreciation
28.02.2017	01.03.2017	-260.00	-2080.00	Monthly Depreciation
31.01.2017	01.02.2017	-260.00	-1820.00	Monthly Depreciation
31.12.2016	03.01.2017	-260.00	-1560.00	Monthly Depreciation
30.11.2016	01.12.2016	-260.00	-1300.00	Monthly Depreciation
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30.09.2015	01.10.2015	-261.11	-783.33	Monthly Depreciation

Exit Process Cancel

Figure 9: Valuation Schedule


Repairs Search Create Maintain Help About

Repair No	Type	Status	Raised Date	Priority	Target Date	Location	No. Jobs	App	Description	Actions
	SRQ	COM	08/11/2017	P4	06/12/2017	YARD	-	-	NOTE ONLY: Tenant advised there is a leak at the water meter. I transferred tenant to Water Corp.	Please Select
	WOR	COM	08/11/2017	P3	10/11/2017	SHOW	2	-	No water supply from shower taps only. PH	Please Select
	SRQ	RAI	08/11/2017	P3	10/11/2017	SHOW	-	-	No water supply from shower taps only. PH	Please Select
	WOR	COM	07/11/2017	P2	08/11/2017	INTL	2	-	Low water pressure to the property. There is a hidden water leak - no visible leak but main water meter is spinning when taps are off. PH	Please Select
	SRQ	RAI	07/11/2017	P2	08/11/2017	INTL	-	-	Low water pressure to the property. There is a hidden water leak - no visible leak but main water meter is spinning when taps are off. PH	Please Select
	WOR	CLO	31/05/2017	P3	02/06/2017	EXTL	2	-	EW front yard tap causes	Please Select

Figure 10: Working Version of Repair Request History

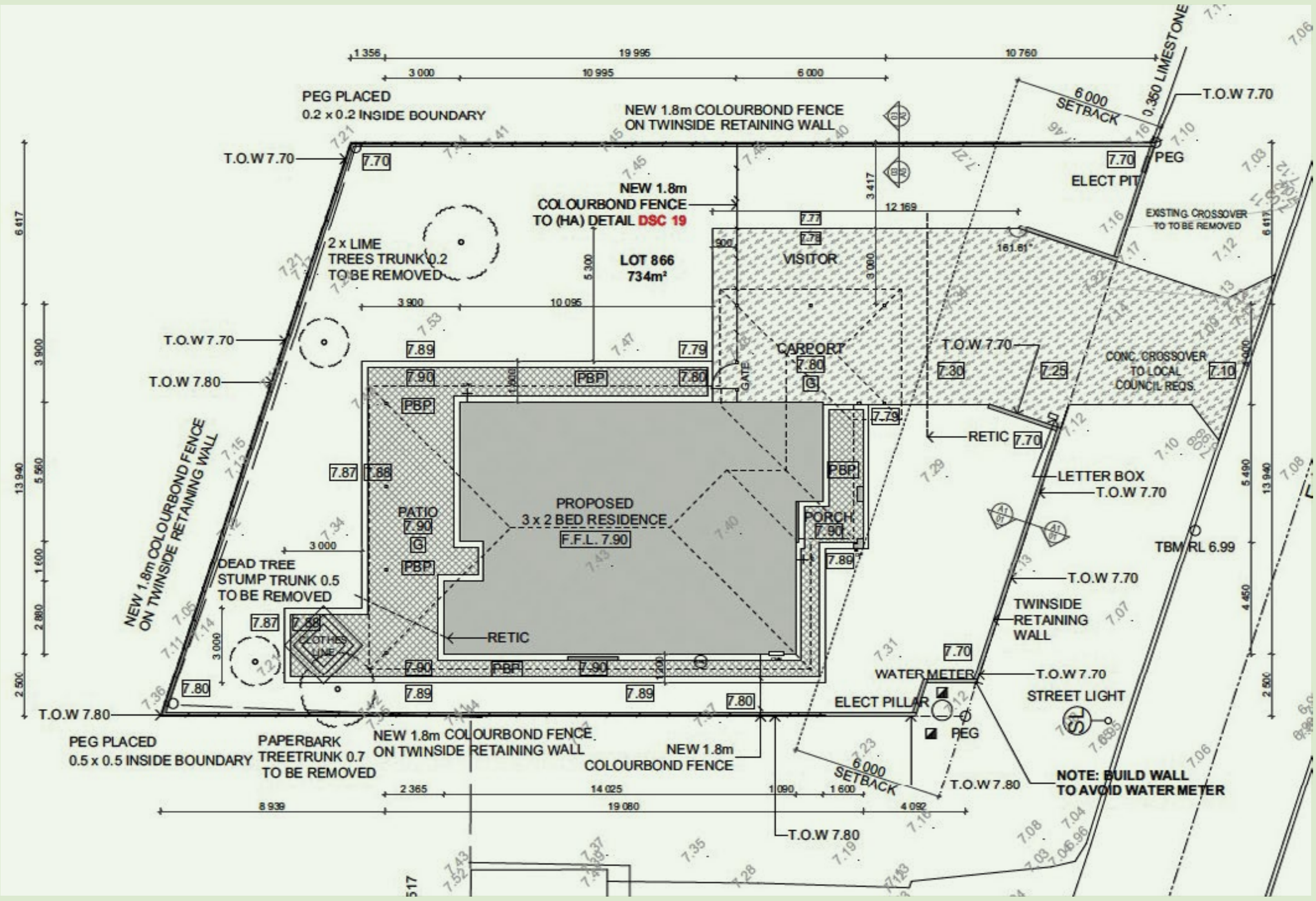


Figure 11: Typical Site Plan

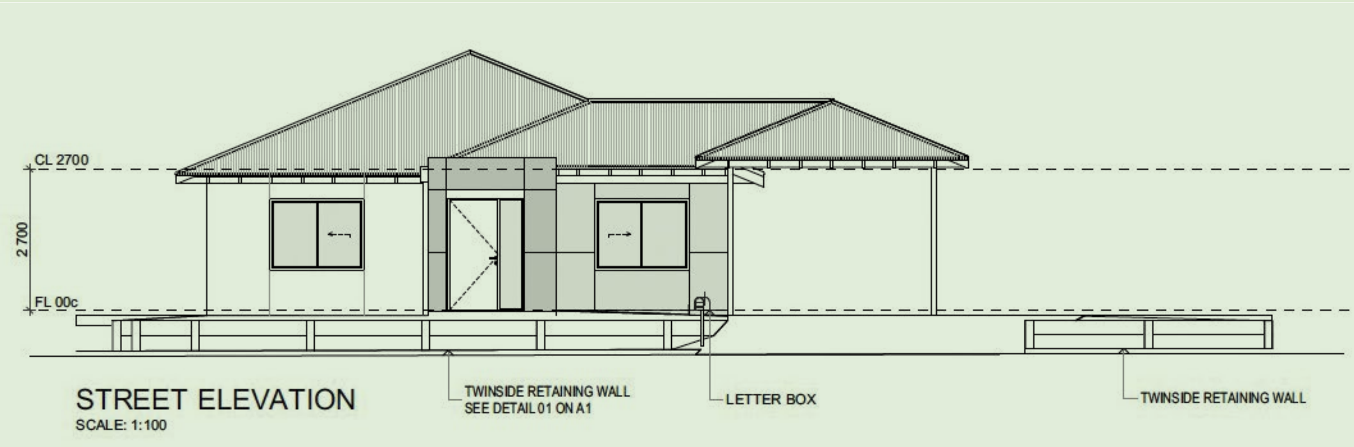


Figure 12: Typical Street Elevation

Figure 11 and Figure 12 show an example site plan and street elevation of a dwelling that is specially designed to meet the needs of a person with a disability. Given that the NDIS is a new program which replaces existing models of delivering outcomes for people with a disability, it is important to be able to map the specifications of current disability housing against the new criteria. Previously, information needed by the NDIA may not have been recorded as it was not required for previous programs and for managing the portfolio. This may mean that the schema for the asset management database will need to be extended to support better identification of categories provided by the NDIA.

1.3.2 Conclusions

The asset management system that is currently used by the WA Department of Communities is a typical 'data-driven' system of the type that currently dominates built environment asset management practices. This can pose constraints, as discussed above.

Changes in funding structures for specific tenants through the NDIS means that the schema within the asset management database needs to be upgraded to support queries required to meet NDIS reporting requirements. The data on housing assets will need to be matched against data on the tenants to be able to report which types of housing with specific levels of support are occupied by tenants with various levels of disability.

2. Building Case Studies

The three building case studies (approximate locations shown in Figure 13) represent the more advanced examples studied across all case studies in this project. The two reasons for this are (i) digital asset management initiatives in the building area are more mature than in infrastructure, with the COBie project for example having been started over 10 years ago; and (ii) building projects are of sufficient size and complexity that the return on investment in digital asset management is easier to quantify and achieve.

Case Study 1 – Curtin University Building 109 represents the current state of achievement within a large initiative by the University in digital asset management over 5 years of activity. The Curtin University team have had the opportunity to learn what works and what doesn't necessarily provide a good return on investment. For example, laser scanning of the exteriors of buildings has allowed the resolution of inconsistencies in dimensioning across various documents. However, the use of laser scanning on interiors has proved much more time consuming over hand gathering of data and dimensions, for the addition of little additional useful information.

Case studies 2 and 3 – James Cook University Science Place Building and Warren Districts Hospital both represent the leading edge in the use of specialist digital asset management software, where the user interface supports a range of queries against various asset management functions and the visual browsing of a virtual representation of the entire facility, with the ability to select an object, group of objects or a system and access the asset management data directly.

Figure 13: Approximate Locations of Building Case Studies

2.1 Building Case Study 1: Curtin University Building 109 (Perth, WA)

2.1.1 Project overview

In 2010, the Curtin University, Properties, Facilities and Development (PF&D) team had 2D floor plans in their facilities management system but the plans were not accurate. A five year plan was put in place which included a shift to Autodesk's Revit as a 3D modelling platform. The first step in improving the Facilities Management (FM) system was to improve the existing data and prepare reliable and accurate floor plans. These accurate floor plans were then fed into WebCentral–Archibus, the Curtin space management and project management system, which supports:

- Capital works
- Space planning
- Operations.

The major user interface displays floor plans in which different zones are presented with different colours. The system also has a GIS view, in which clicking on a room allows the display and editing of the attached information.

The goals of the initial five year plan were revised based on the experience implementing the plan. Curtin University's Properties, Facilities and Development have now progressed two years into the revised five-year plan.

Exterior laser scans have been done on 86 University buildings. These need to be checked by comparing the model to the actual buildings. The LOD (Level of Definition) varies between different usages. They currently use the AutoCAD environment with standards for layering, etc. Changes cannot be made in isolation. The various stakeholders, such as University Security, need to be notified as part of the accountability process. The master documents are currently schematic representations of the campus.

2.1.2 Process of capturing building information

The internal process is that there is an internal Responsible Officer (RO), who is accountable for the project holistically. The RO engages a Lead Consultant (LC) who coordinates the project team and deliverables, including data/documentation. The LC also requests Master documentation from Curtin Building and Services Data Portfolio (drawing services team). Once the project is complete, the RO enforces the delivery of appropriate data from the project (from the LC); however, it is the LC's responsibility to check the completeness and accuracy of the submitted material. The RO then delivers the as-constructed data to the Building and Services Data portfolio (BSD) team (drawing services), who translate the as-constructed data to the internal Master documents. This is then fed back through Curtin services, servers and systems, and closes the loop (Figure 14).

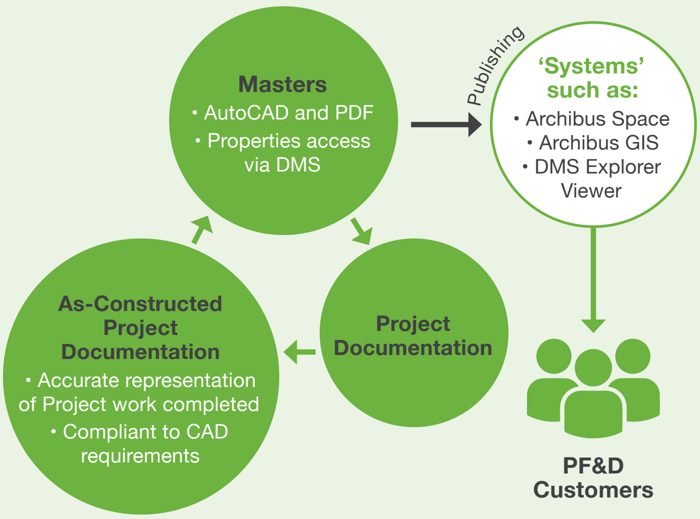


Figure 14: Process of Incorporating Contract Documentation into the Asset Management Systems

Problems and delays in updating asset data may be encountered for various reasons. The common causes of delay are:

- Time taken for as-constructed documents to be issued to the BSD team;
- Incomplete or inaccurate drawings provided;
- Documents do not comply with required standards, which are available on-line;
- Engineering services data is added using external resources. This requires a separate budgetary approval;
- Multiple parties requesting documentation directly from the BSD team.

These issues are addressed within the new Curtin University system by:

- Lead Consultants check all documentation before submitting it to the Responsible Officer;
- Single points of data entry by the Lead Consultant;
- Responsible Officers confirm that as-constructed data is complete before submitting to the BSD team;
- BSD focuses on architectural, interior, space, fire, evacuation and in-ground services;
- External panel of drafting companies update engineering services masters.

The Lead Consultant manages the overall project as part of the Curtin University ‘family’. Revit files may be produced instead of 2D CAD files. With Revit files, the family objects need to be checked instead of the CAD files. The object library is handled externally.

The Lead Consultant manages delivery of manuals for equipment. The exact process depends on the size of the project. Within a project, each level within the contractual hierarchy is meant to manage the processes of the next level down. This means that they coordinate production and check the adequacy and quality of the result.

Figure 15: Curtin University - Bentley (Perth) Campus

Building 109 on Curtin University's Bentley campus (Figure 15) was used as the test-bed for more advanced FM operations. There were often varying dimensions on the documentation of external features of the building. The only way to resolve the ambiguity was to verify actual dimensions.

The building exterior was modelled from laser scans. This means that only the visible surfaces have been captured in the scanning process. Any underlying information needs to be inferred. The laser scanner was used to get accurate representations of the buildings, both externally and internally. It took six weeks to laser scan the interiors, while the models were only completed three months after that. Traditional hand measurement techniques were much quicker, provided the needed data and were much cheaper than trying to laser scan all of the spaces internally. Figure 16 shows the point cloud representation of the building and Figure 17 is the 3D Revit representation derived from the point cloud. Two dimensional plans and elevations can be generated directly from the Revit model (Figure 17). The entire scan to BIM process is shown in Figure 19.

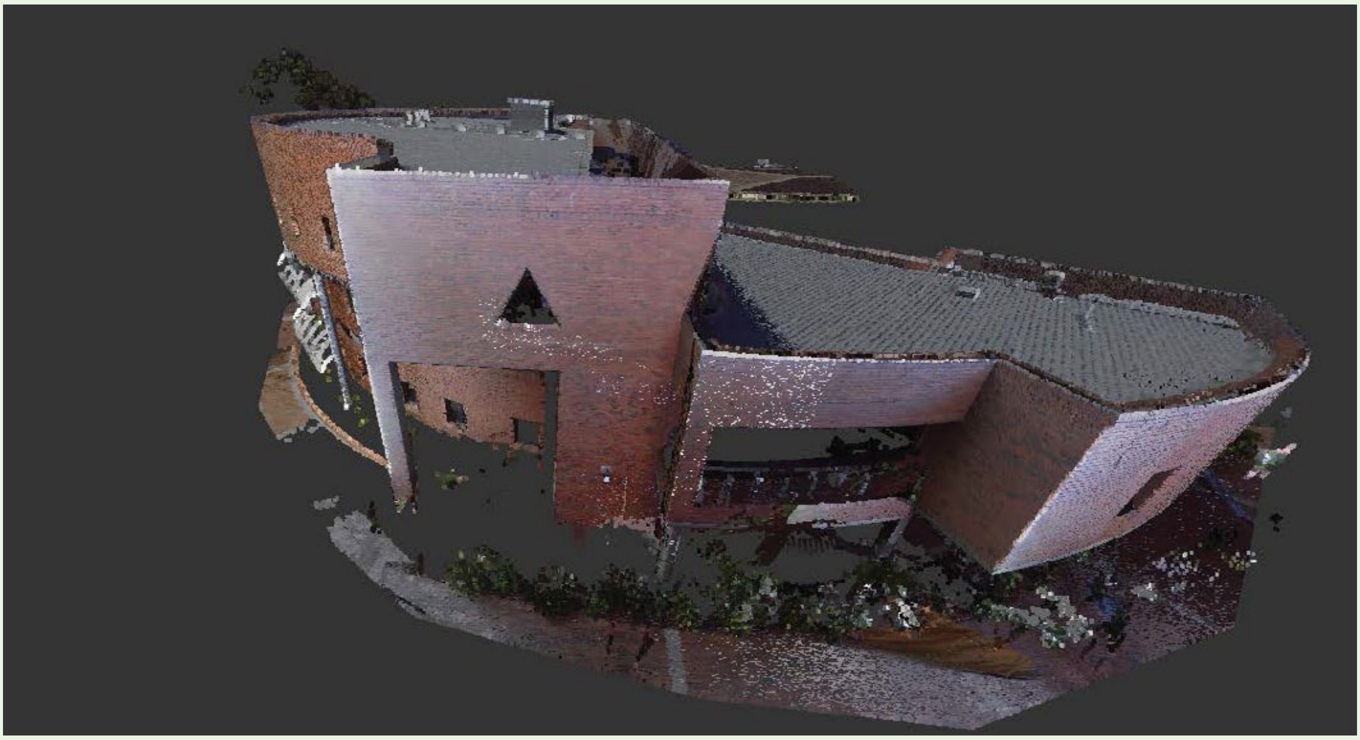


Figure 16: External Laser Scan of Building 109 (point cloud)

Figure 17: Revit Model, a Building Information Model using the Point Cloud Data for Accuracy

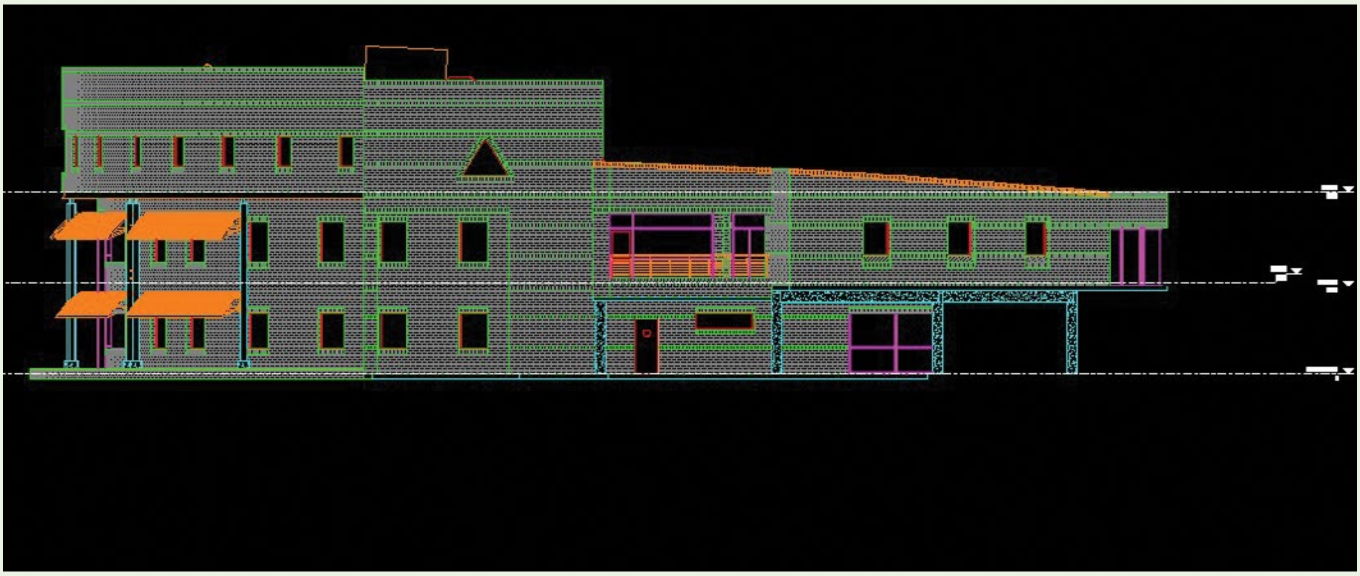


Figure 18: 2D Elevation Generated from BIM Model

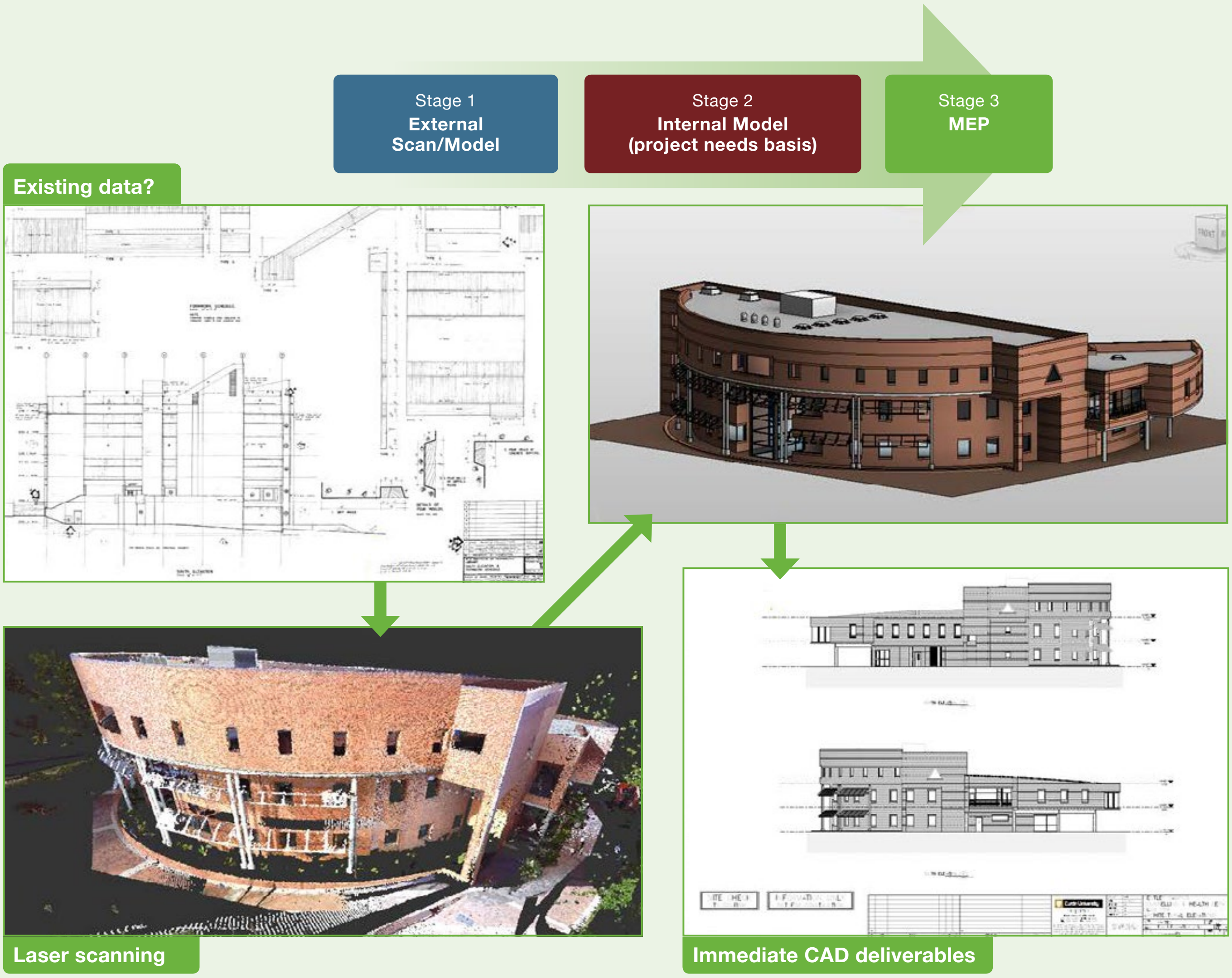


Figure 19: Curtin University Scan to BIM Process

Table 2: Asset Terminology across Curtin University

Alias (SAMP[10] name)	Structures	In-grounds	Public Realm	Planning
	Campus	Campus	Campus	Campus
				Super Lot
Facility	Building	Network	Zone/Garden/Precinct	Development Lot
	Level			
	Room			
Asset	AHU[11], lights, equipment	Valves, pipes, ducts	Furniture, paving, equipment	Space
	Components	Components		

[10] SAMP: Strategic Asset Management Plan
[11] AHU: Air Handling Unit

Currently, no Revit models are linked to the building maintenance systems. Specific maintenance information has not been previously defined for hand over. Curtin University simply took the information provided by the consultants. For example, there were more than 1,290 maintenance documents provided for Building 410 (completed June 2017). This data is in the 'simplest' format possible and is very hard to use. It can be categorised into different services but then the naming is not suitable and there are issues with file names. Curtin PF&D are currently re-evaluating the maintenance manuals as a whole; however, this is associated with a non-BIM environment.

Key issues that have arisen throughout the changes to the asset management process are:

- The definition of 'What is an Asset?' varies across Curtin University departments and functions (Table 2);
- The same term can be used in different ways across the university;
- Asset IDs must be consistent across all systems;
- Room numbers must be stored in Archibus before any relational information can be added, such as ducts. The floor plans must be entered before any other data including contractual information. Hence, this must be done before construction commences;
- The minimum information required for maintenance operations is:
  - Asset ID and asset location;
  - The serviced locations;
  - Warranty information;
  - The last issue that was addressed and who worked on it; and
  - Any asset specific requirements;
- PF&D do 'sanity checks' on as-designed documentation as part of the quality review.

2.1.3 Future plans

In the immediate future, the Curtin University system will have additional functionality:

- Direct import of parameters from Revit into Archibus;
- Testing import of space definitions from Revit into Archibus.

It is intended to use Revit on new projects on the Midland campus.

2.1.4 Conclusions

Curtin University has been working towards a BIM-based asset management system for some time. A thoughtful staged approach was used and this has meant that they have been able to progressively learn from the process without exposing themselves to significant risks. The ongoing staged approach means that this is still a work in progress, with additional functionality to be added in the near future.

The use of laser scanning to obtain definitive data on the exterior of the university buildings has proved very useful. However, using laser scanning to gather data on the interiors has been less successful. More traditional measurement methods have provided the requisite interior information in a timely manner and within acceptable bounds of accuracy.

As with several other case studies, there have been significant issues in supporting the varying concepts and terminologies used by the various stakeholder groups. Using mappings within the database between the varying terminologies used by stakeholders and the harmonised terminology within the database schema can assist in supporting stakeholders in the manner they expect.

2.2 Building Case Study 2: James Cook University Science Place Building (Townsville, QLD)

2.2.1 Project overview

James Cook University (JCU) in northern Queensland (Figure 20), has over 360 buildings and 230,000m² of floor area modelled in Autodesk Revit, linked with their Integrated Workplace Management System (FM:Interact). The University has adopted BIM through the design, construction and operations phases of all new building projects.

Beginning with a CAD/paper-based project management and handover process, JCU identified the need for a BIM-enabled design and continuous data management process. By introducing new technologies, processes and standards, JCU took control of data from the Design Development stage all the way through to handover; ensuring that they had access to the data they needed, when they needed it and in a format they could use.

At the operations stage, the University leveraged the increased availability of space data to improve operational efficiencies and rationalise the University's built footprint.

2.2.2 Challenges

Without a BIM-based process, JCU relied heavily on manual coordination efforts during the construction and handover phases which meant that often conflicts that should have been picked up in the design phase were not discovered until later in the project, leading to delays and cost increases.

At handover, momentum was lost as the operations team struggled to collect the information necessary to properly manage the defects and operations phases of the building lifecycle. Sourcing the right data in useable formats proved difficult, which led to the double handling of data as it was manually entered into management systems.

Improving processes while utilising BIM seemed like the logical next step for the University, as greater emphasis was placed on the cost of projects and operations. Faced with aggressive schedules and tighter budgets, managing the building lifecycle had become an area where there were potential benefits to be realised.

Figure 20: James Cook University Science Place Building

2.2.3 Solutions

Starting from scratch, JCU put together a BIM/FM Working Group to research and examine BIM usage in other organisations and identify the basic requirements that would be the foundation for JCU's project.

A series of data gathering exercises, including digitising of record drawings, on-site truthing and measure-ups, and conversion of CAD drawings, provided the base Revit models while Optical Character Recognition (OCR) scanning of records relating to the buildings and projects provided the preliminary data.

2.2.4 Approach

Having determined what data they had, the BIM/FM team then identified what they wanted. Initially setting out a staged set of BIM specifications, JCU could specify different requirements based on project value or service provider capabilities.

To ensure maximum compatibility with associated systems, JCU specified deliverable requirements for Revit version, Level of Detail, family naming conventions, categorisation and associated parameter naming.

On major projects, building model submission was expected regularly throughout the design development, construction and at handover. In addition to improving coordination between disciplines, as the detail levels of the models improved, stakeholders were able to prepare for occupancy as preliminary data flowed through to linked systems. Not only were the project teams seeing less expensive and time-consuming changes in the construction phase, but the transition to operations proved to be smoother than expected.

2.2.5 BIM for FM

The increasing integration of the building models with JCU systems presented its own opportunities. One area identified by the BIM/FM team was data integrity in the model at each handover. As the amount of data in each model increased rapidly, it became a major task to manually check for compliance with the standards and specifications. There was still also a significant cost in manually updating models handed over to JCU, to a BIM/FM ready state; particularly the data. Revit included some basic standard checking but a more robust solution was needed. Working with Advanced Spatial Technologies Pty Ltd (ASt), JCU began trialling BIMAssure for analysis of project models. Focusing on the rapid creation of shared, standardised rules-based analyses, JCU design staff were able to perform these checks simply by publishing the model to the BIMAssure cloud vault. The model located in the cloud, enabled multiple users on the project to carry out checks on the data, corrections made, and updates synchronised back into Revit on the desktop.

In addition to adopting BIM for projects, the University was also expanding the scope of its Integrated Workplace Management System (IWMS)[12], FM:Interact. Having mapped Revit parameters to the IWMS database, a bi-directional integration with the Revit models meant that as soon as the model was published to the system, the operational data was available to management and front-line operational staff, with all functionality provided through a web browser.

[12] An integrated workplace management system is a software platform that helps organisations optimise the use of workplace resources, including the management of real estate portfolios, infrastructure and facilities assets.

2.2.6 Results

With the building asset data in the IWMS, cleaning, security, maintenance, IT and timetabling staff had the information necessary to do their jobs on their desktop or mobile device immediately. The building fabric data contributed to quicker and more accurate cleaning tenders, IT staff had access to physical network traces before performing works, and room inventories and capacities became suitable for use in JCU's timetabling system.

Efficiency initiatives enabled by a more comprehensive understanding of the University's building stock offset the reduction in government funding. The space types were mapped, allowing for cost modelling of the University's activities carried out versus the maintenance costs associated with those spaces. With an additional feed of Human Resource data, the University began modelling more efficient space allocations, comparing the staff assigned to a building with the amount and type of space in that building; the result being that the University could reduce the total built footprint while improving services to the students.

2.2.7 Conclusions

The use of BIM to support asset management at James Cook University has had a significant impact. The increased coordination between disciplines has resulted in fewer delays while the ability to produce visualisations within the context of the campus has improved overall engagement with the University community. Arguably the greatest change though, has been in operations, where improved visibility of building asset data has streamlined operations, greatly improved the consistency of data used amongst operational units and helped promote a positive awareness of FM operations throughout the organisation.

James Cook University has embraced the capabilities of BIM to improve organisational decision making and enhance planning exercises. BIM data has contributed to the University's 10-year development planning, Strategic Asset Management Plan, Activity Based Cost Modelling and various space rationalisation projects.

2.3 Building Case Study 3: Warren Districts Hospital (Manjimup, WA)

2.3.1 Project overview

The construction of Warren Districts Hospital (WDH) (Figure 21), was a A$37.6 million project to replace the existing ageing health facility at Manjimup, south of Perth in Western Australia, with a state-of-the-art building for the Western Australia Country Health Services (WACHS).

Building Management and Works, Department of Finance, Western Australia, as part of their tender process, had a requirement for the main contractor to be able to demonstrate how the final Building Information Model (BIM) would be used to help drive ongoing operations and maintenance. Pindan Constructions successfully completed the building project using BIM and the building is now operational. The facilities management system 'FM:Interact' was piloted for BIM-FM using the final as-built model provided by Pindan, completed to LOD500[13], and the model was updated to BIMFM level status by Advanced Spatial Technologies Pty Ltd (ASt).

Various versions of Pindan's models were provided to ASt, produced by their modelling consultant (BIMFire). The design model originally produced by STH Architects was passed to BIMFire, who rebuilt the model for Pindan to suit construction use. The building model used for construction purposes was very successful and the construction of the hospital has been a smooth operation. This included the use of schedules and all of the construction-based detailing (shop drawings and the like).

The follow-up process of using the as-constructed version of the construction model, modified for facilities operations purposes, became the subject of this case study.

Figure 21: Warren Districts Hospital – Rendered Perspective

[13] LOD500: BIM Level of Development 500

2.3.2 Objectives

ASt's main goal and objective was to integrate the Warren Districts Hospital BIM with the IWMS FM system FM:Interact and demonstrate that the BIM could also be used for operational purposes to the advantage of WACHS. This would test the ability to take an as-built BIM and convert it into a fully functional BIM-FM solution that was capable of serving the operational requirements of the hospital's users and the WACHS department. This included building space, assets and maintenance and other FM functions.

2.3.3 Challenges

2.3.3.1 Data Management

ASt initially reviewed the data contained within the model to determine what data was relevant for each part of the asset system within the FM:Interact system. For example, the building equipment asset catalogue would require a description of the asset, the manufacturer and model number, as a minimum, to enable the system to generate a list with no duplications.

Initially, ASt also had to establish exactly what data to use in the BIM, which meant reviewing all assets and asset priorities. Typically, assets of high priority included: essential services, followed by critical systems, then major plant and equipment.

For the pilot with WDH, ASt focused on electrical items, furniture, services, plant and equipment to demonstrate how assets are automatically found in the Revit building model and synchronised with the FM system database.

2.3.3.2 Building Complexity

The WDH building model was complex in the sense that it was equivalent to several buildings combined as one large model. There was a significantly large list of assets in the model, containing a high level of detailed information that had been entered in the construction and as-built phase.

With such a detailed level of asset data information held in the BIM model, the only asset information lacking would be historical data not contained in the model. It was acknowledged that this data could be entered directly into the FM system.

2.3.3.3 Integration with Object Libraries (Families)

Integration with so many asset categories brings with it the issue of having to determine what information from each group is important or a priority to the management of the facility. This along with the large amount of different Revit families, all constructed differently using different data types and lengths, only added to the problem. The information referenced in the ABAB (Australasian BIM Advisory Board) Asset Information Requirements Guide was found to be of high value in determining which assets to use in the FM system.

As the starting point was an as-built model and there had been no prior opportunity to define FM requirements for the model, there was a need to make changes and match fields in the FM system in order for this to work. With an open configurable FM system like FM:Interact, having the flexibility to add/modify tables, fields and views was important in order to accommodate the different data. After synchronising the asset information from Revit into the FM system, it was then easy to select an asset in the FM system, see all of the asset details and quickly zoom to the relevant room or location.

2.3.4 Solutions

2.3.4.1 BIM

The building model was supplied in Autodesk Revit format from the construction company's BIM Consultant (BIMFire).

Using Autodesk Revit, ASt initially reviewed the asset schedules, to better understand the different asset types in the model that would be used in the FM system. There would be a range of users of the assets such as engineers, facilities officers, maintenance technicians, purchasing officers and requestors.

The schedules also helped to understand how to organise the data into asset types and asset instances, making it easier to break up and extract from Revit. The user would defer to the ISO standards and standards being developed by ABAB to determine the different priorities of assets required, from initial handover to the longer-term requirement. Doing this also makes it easier to determine if the data integrity is maintained. Data comparisons between the Revit schedules and the data imported to FM:Interact are easily achieved using Microsoft Excel.

2.3.4.2 BIM Assure

ASt used technology from Invicara (BIM Assure), and the rule-based checking processes to quality check the model data for completeness and correctness, and identify any missing or wrong data.

An immediate advantage from this process is that the Model is published into the BIM Assure cloud vault, where secure account access is provided for any project team member as required. Each team member can review/check, add, modify and update data as required in the BIM model located in the cloud. That data can then be synchronised back into the Revit model on the desktop. This allows better checking and update of the model data by the discipline specialists (AEC consultants, FM, Project Managers, etc.), a process which can be difficult to manage by model operators, in a Revit environment at desktop level.

Ideally this practice and technology should be used earlier in the process throughout the design and construct phase, and effectively replace the traditional as-built update normally done at the end of the project. The practice provides easier and more regular checks through the entire design and construct phases. However, the as-built construction model was checked with BIM Assure as part of the pilot. Whilst this was not an exhaustive check, issues was discovered with the model that were otherwise difficult to find, which contributed value to the pilot, for improved data, pre-flight to linking the BIM to the FM system.

2.3.4.3 FM:Interact (BIM-FM Lifecycle Model)

ASt used FM:Interact IWMS as the platform for linking the Revit model to the FM system.

The technology provides for a synchronised bi-directional link between the asset data in the model and asset data held in the FM system's database. With this technology the FM team does not need to have Revit operating and model maintenance skills. They can access the model's space and asset data through a web page browser, for ongoing asset tracking and maintenance and to manage their facility.

The FM:Interact tool allows mapping of family parameters in the Revit model and the FM:Interact IWMS, and allows the user to determine which is the authoritative data source (Revit or FM:Interact). Changes to data need never be lost to any part of the system and can be managed to ensure accuracy.

2.3.4.4 Plugins

Both the BIM Assure and FM:Interact technologies provide plugins to interface with Revit.

The FM:Interact plugin allows information to flow both ways between Revit and FM:Interact. The advantage of this is that building facilities managers are able to make changes in the FM system and automatically update the Revit model. The user can decide if Revit or the FM system is the authority source of data.

Autodesk Dynamo Studio plugin is a visual programming paradigm available as an alternative method for extracting data from Revit. Synchronising assets is not without its challenges. Given the data mismatch and the number of changes that are required to achieve an accurate exchange of data from Revit to FM, the user may not always get the control they desire. This can lead to new items not being added to the catalogue correctly which can result in creating a new catalogue item for each item of inventory.

Greater control can be found using Dynamo Studio. This adds an extra step into the process, but it retains the two-way exchange of information between Revit and FM. Greater control and verification of information is also possible as there is a stage that exports the information to Microsoft Excel, before it is eventually loaded into FM:Interact.

When the information is in a human readable format within Microsoft Excel, the user can carry out further testing on the data to improve the accuracy.

The user must then add intelligence to the spreadsheet to ensure the catalogue numbers being assigned are unique. This can easily be achieved using Visual Basic and by reading in the current FM catalogues.

2.3.4.5 Observations

The WDH project followed the traditional method for handover of as-built records to the building owner.

This pilot project found that delivery of best quality BIM as-built models requires better quality control measures and the process should start at the project planning stage.

The best practice now being used internationally requires that the construction model is updated for FM use to ensure that the data is complete, correct and suitable for operational uses. For example, the WDH model contained three different room numbering systems; the Revit space number, the STH architects design room number and the new space numbers added to the model in the construction phase (the WACHS room numbering standard used across their entire hospital asset portfolio).

ASt used BIM Assure cloud based BIM checking to review the model for items such as room numbers and look for possible missing, incorrect, or unusable data. Another example of the value of BIM Assure is where assets were placed on a wall such as an A/C unit. The FM system would attempt to find the asset; however, it would only look for assets related to a floor. Also, if the cutline set for a floor plan view in Revit was well below the underside of the slab, it may not find any asset above the cutline.

Mechanical, Electrical and Plumbing (MEP) sub-contractors may have different design practices in how they produce their models; for instance the naming of floors. If this is not agreed between all parties then it will be difficult to match information in the system for each asset, between architectural and any linked models. The same is true for the naming of each phase of the project. Uniformity of data between models is very important and a BIM management plan should include early liaison between the BIM designers and the operational team, and best practice of model data checking throughout the project.

The Hospital Engineer or Facility Manager, representing the building owner, needs to become more familiar with the requirements for asset use and the priorities and best practice processes for success. The modellers need early advice on the requirements for BIM-FM for the building assets and need better guidelines and standards for using digital assets.

When building models are used to provide digital asset information for the FM system, it is best that the correctness, accuracy and completeness of the information is validated at each stage of the process. This includes early agreement on format of codes in the model. For success, it is the information that must be seen as one of the most important outputs and everybody has their part to play in ensuring this end goal is upheld at each stage.

With best practices applied and correct data being provided from the models it will be an increasingly simple task to handover models and produce a fully functional facilities management solution. The repeatability of the process is what will make this possible. By continually accessing the outcome of each building project and the resulting FM solution, changes to the process can be made in order to benefit from the lessons learned and strive towards ensuring a successful outcome for the building owner.

2.3.4.6 Lessons Learned

ASt has uploaded other building models from other sources and the WDH model proved to be more challenging than most, mainly due to the evolution of the model from initial design and update through the construction phase. With newer processes and technology for reviewing and checking the model earlier in the design and construct phases, a much smoother process can be expected, as experienced with other models.

Model size and performance needs to be considered; refer to the *Digital Asset Information Management: A Guide and Manual* chapter on ‘Guidelines for creating BIM-FM Models’.

Best practices should be observed to ensure the data in the BIM is complete, correct and at current state at handover,

before attempting to link the BIM to the FM system. There is value in using BIM quality checking technology, to pre-flight check building models prior to linking with FM systems. The process and technology ASt used on the WDH model, allowed all members on the project team to engage: AEC consultants, constructors and the building owners' representatives.

The operations facilities team should work closely with the BIM design and construct team, as early as possible in the design and construct process, in order to achieve the best outcomes when using BIM for FM operations.

For the WDH case study pilot, ASt simply registered and connected the Revit model to the FM:Interact system and uploaded all of the assets available in the model to the FM system. For the purpose of the pilot, further time was not spent assessing the asset priorities as would normally happen on a BIM-FM project. The relationship of asset selection priorities could also be configured through filtering in the FM system. For example, any assets that related to say 'Maintenance', 'Regulatory compliance' or 'Risk' could easily be filtered by category or attribute for viewing or reporting use.

2.3.4.7 Results

ASt checked the BIM model using BIM Assure as part of conversion of the model to BIM-FM and found a number of data updates and changes required in the model, prior to linking the IWMS (CAFM) System. The BIM-FM Revit model was linked to the FM system, all spaces and assets uploaded with a bi-directional link and published both as 2D floor plans and a 3D model.

The digital asset information and locations are viewable through a browser by all user roles as required, with appropriate access and permissions set.

Assets in the model were transferred to the FM system with a bi-directional link for easy update either in the BIM or the FM system and can be synchronised as required. Assets were transferred across to the FM system by type and instance and categorised as either maintainable or non-maintainable type assets. They are easily findable in the FM system 2D plans or 3D model.

The system allowed user access from both desktop and mobile via the web browser. ASt are currently setting up a web page that will provide live interaction with the system.

2.3.5 Conclusions

It is preferable that the intention to use a BIM model for asset management is recognised early in the project design process. This allows the design team to ensure that appropriate values are entered during the design and documentation stages. This then provides a good basis for the entry of the necessary data during construction to provide the as-built model.

All information specific to the construction process, such as working names for spaces, should be removed before adding data to the asset management model. Only names and IDs that will be used during building operation should be available in the asset model.

A reliable method of checking the data supplied to the asset management team is necessary to ensure that the data provides appropriate coverage of the assets that will be managed, the attributes are named appropriately and that the values against the attributes are within range.

3. Transport Infrastructure Case Studies

There are four case studies presented for the transport infrastructure sector, spread nationally across three Australian states: New South Wales (NSW), Western Australia (WA) and Victoria (VIC) (Figure 22).

Case Study 1 – the Armadale Road Upgrade project (located in WA) provides an example of applying Building Information Modelling (BIM)/Digital Engineering (DE) for road asset lifecycle management. The Project team has significant experience in investigating the requirements of as-built BIM models and how to automatically transform BIM data into the existing road operation and maintenance systems. *The Digital Asset Information Management (DAIM): a Guide and Manual*, developed through the Sustainable Built Environment National Research Centre's Project 2.51[14], was tested in this case study and used as a basis to developing the Road Asset Information Requirement, Road Asset Classification System and Road Location Referencing System that are specific to this case. This upgrade is still under construction and more analysis will be done in the future.

Case Study 2 – the Forrestfield Airport Link project (located in WA) provides an example of applying BIM/DE for rail asset lifecycle management. The Project's Asset Management Team has developed a detailed asset information requirement to guide the asset information creation and updating during the project design, construction and handover stages. Any equipment provided by the Project Client (e.g. ticketing machines, fare gates) must be included in the model, with all characteristics and to the same quality and detail as the rest of the required model. In addition, a number of Asset Information Templates have been created to assure the rail asset information is accurately created, maintained and transferred through project lifecycles.

Case Study 3 – the New Grafton Bridge project (located in NSW) provides an example of applying BIM/DE for bridge asset lifecycle management. BIM had been used in the design and construction stages of this project, such as bridge design optimisation, flood simulation and analysis, construction simulation and optimisation, and lifting analysis. In order to continually use the 3D Bridge Information Model to support the bridge operation and maintenance, the proposed DAIM developed in SBEnrc Project 2.51 is now being used to guide the 3D BIM model enrichment; such as bridge element re-classification, additional attributes adding and geographic location linking.

Case Study 4 – the use of DAIM in VicRoads (located in VIC) provides an example of applying DAIM to facilitate digital transformation at an enterprise level, in this case in VicRoads, the Victorian Government's principal road agency. The aim of this case study was to: (1) understand VicRoads' current road asset operation and maintenance processes; (2) understand VicRoads' current asset management tools or platforms including their functions, data inputs and outputs, and underlying data schemas; and (3) benchmark VicRoads' road asset management practice in terms of digitalisation.

Figure 22: Project Location of Case Studies

[14] SBEnrc Project 2.51: https://sbenrc.com.au/research-programs/2-51/

3.1 Transport Case Study 1: Armadale Road Upgrade (Perth, WA)

3.1.1 Project overview

Armadale Road is a strategic freight route connecting the South West and the South East corridors of Perth, the capital city of Western Australia. It is one of the main east-west links within the Perth metropolitan transport network. The link passes through industrial areas, rural subdivisions, recently developed and planned residential subdivisions and connects the Armadale sub-regional centre and Albany Highway, forming part of the route to Fremantle Port, the principal port servicing Perth and surrounding regions.

Current traffic counts show that 27,000 vehicles per day use Armadale Road between Tapper Road and Warton Road, while 18,000 vehicles per day use Warton Road to Anstey Road (as shown in Figure 23).

The Armadale Road Upgrade project (as shown in Figure 24) includes the duplication of a 6.9 km section of Armadale Road from Tapper Road to Anstey Road to dual carriageway standard including: (1) intersection upgrades at Nicholson Road, Wright Road, Ghostgum Avenue, Liddelow Road; and Rossiter Avenue; and (2) new shared pedestrian and cyclist facilities along the length of the project.

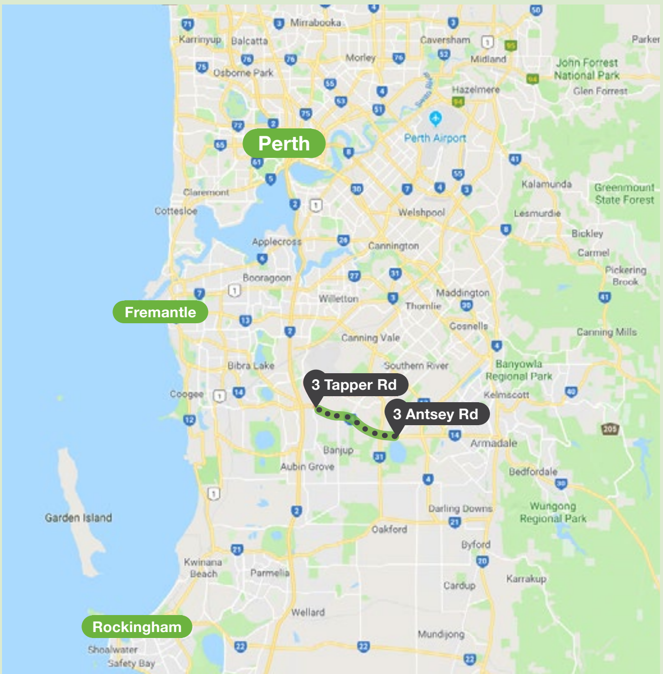


Figure 23: Project Location of Case Study One

Figure 24: Digital Engineering (DE) Model of the Armadale Road Upgrade project (Perth, WA)

The total cost of this project is around A$145 million[15], which is funded by the Federal Australian and Western Australia State governments. The detailed work scope includes:

- Design and construction of Armadale Road duplication from Straight Line Kilometre (SLK)[16] 7.99 (Anstey Road) to SLK 14.95 (Tapper Road) in accordance with the following:
  - Duplication from Anstey Road to Tapper Road to provide a new westbound carriageway and upgrade of the existing carriageway for Armadale Road to form a dual carriageway cross-section comprising 2 lanes in each direction with provision for a future 3 lane configuration in each direction;
  - An at-grade signalised intersection at the Armadale Road (SLK 9.38) and Nicholson Road (SLK 3.96);
  - A priced option for the ultimate grade-separated roundabout at the intersection of Armadale Road (SLK 9.38) and Nicholson Road (SLK 3.96) is included;
  - An at-grade left-in/left-out intersection for Rossiter Avenue with Armadale Road (SLK 10.47);
  - An at-grade 4 arm roundabout at the intersection of Armadale Road (SLK 11.12), Taylor Road and Wright Road;
  - An at-grade signalised T-intersection of Warton Road with Armadale Road (SLK 12.10) utilising the existing configuration;
  - An at-grade 3 arm roundabout at the intersection of Armadale Road (SLK 13.02), Liddelow Road in the project case, an additional northern leg forms part of the ultimate configuration;
  - An at-grade partially signalised seagull intersection[17] with Armadale Road (SLK 14.20) and Ghostgum Avenue (formerly Fraser Road). A right-turn acceleration lane from Ghostgum Avenue is provided in the project case. The ultimate configuration will be a left in/left out intersection;
  - Design of the tie-ins to the existing cross-sections of Armadale Road at Anstey Road and Tapper Road;
  - A principal shared path (i.e. shared paths for pedestrians, cyclists and people with disabilities) on the northern side of Armadale Road to be connected to the principle shared path on the south side of Armadale Road at Anstey Road roundabout;
  - Requirements for noise walls and possibly on-property treatments for more isolated residents.
- A grade-separated bridge is proposed at the intersection of Armadale Road/Nicholson Road as part of the priced option works. The bridge is required to span the proposed two lane roundabout and minimise impacts to existing services.
- Other structures are likely to comprise of minor retaining walls and small culverts.
- The works includes the provision of access to developments on the route and the upgrade of Nicholson Road to the north to connect to the recently upgraded section.
- Traffic signal modifications and upgrades to be made at Warton Road and Nicholson Road.
- Design and construction of a principle shared path along the northern verge of Armadale Road for the length of the scheme, with existing paths and connections adjusted to tie into the proposed new works. The path should connect to the existing path on the south side of Anstey Road.

[15] All costs are in Australian dollars (2018) unless otherwise specified.

[16] SLK is a linear system of measurement used by Main Roads Western Australia (Government of Western Australia) to reference the longitudinal position of assets or asset information on a road.

[17] A seagull intersection is a type of three-way road intersection, usually used on high traffic volume roads and dual carriageways.

3.1.1.1 Project Team Responsibilities

Defined role	Responsibility in Digital Engineering Execution Plan (DEEP) development	Delivery responsibility
Project Manager	Overview	• Manages and coordinates project execution and DE
Digital Engineering Lead	Prepare and maintain the DEEP	• Coordination and review • Leads DE execution
Federated Model Manager	Inputs content specific to the Federated Model	• Coordinates model inputs • 3D coordination and clash detection of existing and design models • Execute clash detection, generate report and distribute to relevant parties • Federation of models and publishing of the NWD[18] files • Audit models and check against DEEP requirements
Model Managers		
Structural Team Civil Team Intelligent Traffic System/ Electrical Team Utilities Team Drainage Team	Inputs content specific to individual discipline models	• Map DE use for design • Lead development of tools for DE modelling for design • Leads the development and quality control of the discipline models • Manages the outputs for model exchange

[18] NWD is a Navisworks File Format. When you save to a NWD file, all loaded models, the scene's environment, the current view and favourite viewpoints (including redlines and comments) are all saved to a single file.

3.1.1.2 Digital Engineering Collaboration Process

Figure 25 illustrates the digital engineering collaboration process. A federated model is a combined BIM model that has been compiled by amalgamating several different models (i.e. models of Environment, Services, Roads, Drainage, Structural, ITS and Miscellaneous) into one. The federated BIM model will then be used for clash detection, supporting project procurement and automating field survey. The integration of the federated BIM model and Geographic Information System (GIS) can be utilised to manage construction permits. All the BIM and GIS data can also be linked with other relevant systems, such as the Main Roads Western Australia (MRWA) Integrated Road Information System (IRIS) and Aconex. IRIS is MRWA's corporate road information database, which stores corporate road information essential to the effective management of the road network, including road inventory, road condition and road use data, as well as crashes and administrative data. Aconex is a cloud-based, multi-company project collaboration solution for construction and engineering.

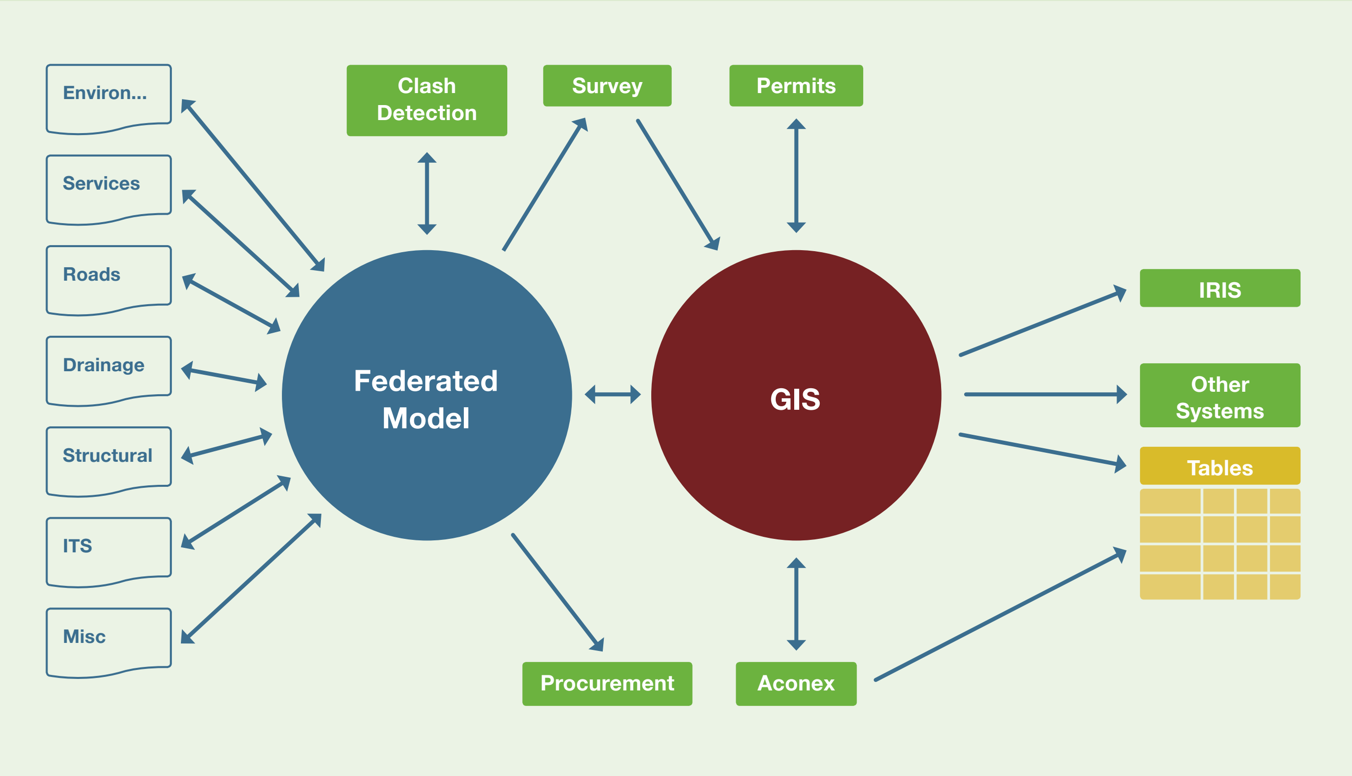


Figure 25: Digital Engineering Collaboration Process

Austroads Data Standard for road management and investment – Version D2V2 – Data items

Function	Group	Document Section	Document Subsection	Document Unique Ref	Document Combined Ref	Data Item Category	Data Item Category Rank	Sophistication Level	Design Team	Construction Team	Hand Over	MRIA	Armadale Rd Dual	Appendix A & B Code & Function Lists			
FUNCTION	GROUP					PURPOSE		SOPH						Code	Name	Function	Ref
Inventory	Vehicle Crossings	8.3	32	1	8.3.32.1	D	2	1				Y		cross_mat	Vehicle crossing material	Inventory-Vehicle Crossings	8.3.32.1
Inventory	Vehicle Crossings	8.3	32	2	8.3.32.2	D	2	1				Y		cross_typ	Vehicle crossing type	Inventory-Vehicle Crossings	8.3.32.2
Inventory	Vehicle Crossings	8.3	32	3	8.3.32.3	D	2	2				Y		cross_dep	Vehicle crossing depth	Inventory-Vehicle Crossings	8.3.32.3
Inventory	Vehicle Crossings	8.3	32	4	8.3.32.4	D	2	2				Y		cross_reo	Vehicle crossing reinforcing mesh present	Inventory-Vehicle Crossings	8.3.32.4
Inventory	Vehicle Crossings	8.3	32	5	8.3.32.5	D	2	2				Y		cross_wid	Vehicle crossing width excluding splays	Inventory-Vehicle Crossings	8.3.32.5
Inventory	Vehicle Crossings	8.3	32	6	8.3.32.6	D	2	3				Y		crs_b_dep	Vehicle crossing basecourse depth	Inventory-Vehicle Crossings	8.3.32.6
Inventory	Vehicle Crossings	8.3	32	7	8.3.32.7	D	2	3				Y		crs_b_typ	Vehicle crossing base course type	Inventory-Vehicle Crossings	8.3.32.7
Inventory	Vehicle Crossings	8.3	32	8	8.3.32.8	D	2	3				Y		crs_s_dep	Vehicle crossing subbase course depth	Inventory-Vehicle Crossings	8.3.32.8
Inventory	Vehicle Crossings	8.3	32	9	8.3.32.9	D	2	3				Y		crs_s_typ	Vehicle crossing subbase course type	Inventory-Vehicle Crossings	8.3.32.9

Figure 26: The Master Data Standard Developed for the Armadale Road Project

3.1.2 Armadale Road: Master Data Management

Collection of road asset data in accordance with a common standard will facilitate more efficient and effective management and sharing of that data. The master data management standard for this project (as shown in Figure 26) was developed based on the Austroads Data Standard for Road Management and Investment. The standard covers the following eight key data types:

1. Inventory;
2. Infrastructure Performance;
3. Works and Costs;
4. Access;
5. Demand;
6. Classification;
7. Condition;
8. Customer Levels of Service.

Asset data items presented in this Standard cover the whole-of-life management of assets required to support and substantiate decisions made over the lifecycle. These decisions include, but are not limited to, the following:

1. Investment management requirements including asset capitalisation and whole-of-life costs;
2. Asset handover requirements including asset acceptance information; and
3. Asset configuration change requirements including asset approvals or sub-component approvals, new assets, configuration and operational changes, including changes in asset strategy and concessions to Standards.

3.1.3 Armadale Road: Asset Information Requirement

The Asset Information Requirement is developed to a Level of Definition (LOD)[19] that appropriately defines the design intent at each delivery milestone.

3.1.3.1 Digital Terrain Model

The Digital Terrain Model (DTM) is derived from data from a number of sources provided by the MRWA. Reviews have been undertaken and identified anomalies raised with MRWA.

The Survey DTM models include:

- Existing features to MRWA Digital Ground Survey Standard 67-08-43[20]
- Filtered Light Detection and Ranging (LiDAR) points. The point cloud is a three-dimensional discrete point, including not only ground points but also artificial structures (such as houses, chimneys, towers, power lines, etc.) or natural vegetation (trees, shrubs or grass). In order to get the ground point, the point cloud data must be filtered to prepare data for the subsequent production.

3.1.3.2 Civil Model

The civil model includes the civil design geometry, earthworks and other surface features, including:

- Earthworks including cut and fill embankments and side drains
- Road pavements
- Kerb
- Road safety barriers; rigid, flexible and semi-flexible
- Lane marking including longitudinal lane lines, transverse markings, chevrons, turn lines and pavement symbols markings

The Construction Model provided for the civil design includes:

- Control lines (for set-out)
- 3D Feature Strings
- Finished Surface Triangulated Irregular Network (TIN).

The civil model is provided across a number of models and associated CAD files. Some elements are provided for set-out and can be relied upon for set-out, and other elements are provided for information only.

3.1.3.3 Structural Model

The structural design includes bridges and other miscellaneous structures, such as retaining walls, gantries and special drainage features, e.g. large pits.

The structural design models typically include:

3.1.3.4 Substructure

- Piles and pile caps
- Piers
- Abutments including footings, columns, cap and skirt beams and abutment protection including toe levels
- Wing walls
- Mechanically stabilised earth walls
- Bridge retaining walls

3.1.3.5 Superstructure

- Deck surface (design levels)
- Beams, deck units and transverse bars/girders (with assumed hog), diaphragms
- Bridge approach slabs
- Drainage penetrations
- Expansion joints and cover plates (to indicate location on bridge deck. No detail required for finger joints, etc.)
- Barriers/bridge kerbs (with precast/fabrication unit breakdown and cast-in place elements such as hold-down bolts)
- Deck wearing surface
- Bridge lighting/balustrades and safety rails (including cast-in place elements such as hold-down bolts)
- Screens: noise/visual/safety (including cast-in place elements such as hold-down bolts)

[19] LOD is a conceptual framework that defines the extent to which model elements are defined both graphically and non-graphically refer PAS1192-2:2013 Section 9.8. This definition provides confidence around model maturity onto which a degree of reliability can be applied for decision-making at each of the respective project stages.

[20] The Digital Ground Survey Standard is available at: https://www.mainroads.wa.gov.au/Documents/67-08-43%20Digital%20Ground%20Survey%20Standard.RCN-D12%5E23434824.PDF

3.1.3.6 Drainage Model

The drainage model includes:

- Cross culverts
- Designed pipes including internal and external diameters with invert levels for entrance and exit points to enable clash detection with existing elements and design elements
- Simplified gully pits, manholes, field inlets. The simplified models do not include details such as lintels, aprons, etc.

3.1.3.7 Utilities Model

The utilities model includes:

- Existing utility services information modelled using the data from a number of sources, including:
  - Dial Before You Dig data
  - Survey data provided by MRWA
  - Survey data from Public Utility Plant (PUP) investigations undertaken in preparing the design
  - As-constructed data from utility asset owners.
- Modelled utilities attributed with, as a minimum; owner, size, status, material, source of information, original model name, original function name and quality level. The quality levels assigned are in line with the MRWA Surveying Standards and Australian Standard AS5488-2013: Classification of Subsurface Utility Information.
- Relocated and new utilities that are required and attributes as provided for existing utilities.

3.1.3.8 Intelligent Traffic System/Electrical Model

The Intelligent Traffic System (ITS) model deliverables include:

- Light poles (structural support in the bridge model)
- CCTV poles
- Emergency phones
- Traffic signals poles, pits, conduits and controllers cabinets
- Variable messaging sign gantries (structural support in the bridge model)
- Vehicle detection system loops/cabinets
- Electrical and communication pits/conduits
- Electrical transformers/substations.

3.1.3.9 Federated Model

The Federated Model includes the following for information:

- Verge furniture to include light poles and foundations, signage and foundations, and noise walls;
- Lighting structures including footings;
- Indicative electrical/communications conduits modelled at a constant depth below surface level with locations, external sizes and type to enable clash detection with existing elements and design elements.

3.1.4 Armadale Road: Asset Information Handover Process

3.1.4.1 Workflow

In order to efficiently handover the DE models in terms of required LOD and data accuracy, five specific workflows were developed for delivering the Structural, Drainage, Intelligent Traffic System, Utility and Civil models, respectively. Figure 27 illustrates an example of the utility information model handover process. All the data, including survey and sub-surface data, will be imported into the 12d platform[21] for utility design, 3D modelling and data processing.

The main output is an Industry Foundation Classes (IFC)-based 3D model which is a platform-neutral data model.

3.1.4.2 Data/Information Quality Check

All project deliverables (i.e. DE models) are subject to a Technical Quality Review (TQR) procedure prior to issue. The individual models are checked for technical accuracy by suitably experienced, independent reviewers and assessed for correctness and completeness by qualified lead verifiers. Where other deliverables are derived from the models, i.e. drawings, schedule quantities, etc. these deliverables are also subject to a TQR Check.

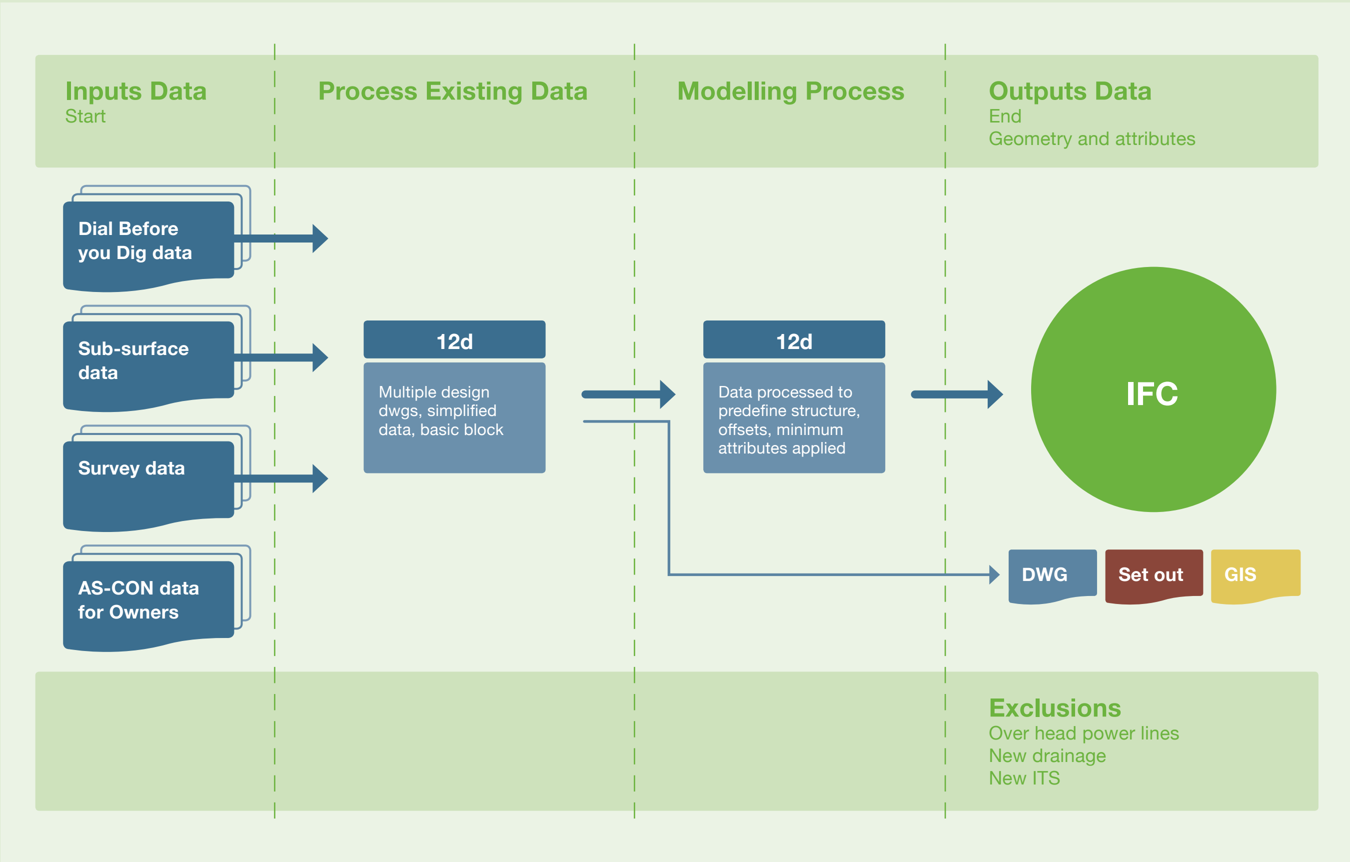


Figure 27: Utility Information Model Handover Process

[21] 12d Model is a powerful terrain modelling, surveying and civil engineering software package. It is used in more than 55 countries worldwide and widely-used in Australia and New Zealand: https://www.12d.com/

3.1.5 Armadale Road: Digital Asset Information Management Platform

For this case study, all the engineering and construction data from the BIM/DE models is converted or linked to the IRIS system for managing the road asset during the operation and maintenance stages. In order to facilitate the data transformation from BIM/DE models to IRIS, the client (i.e. MRWA) requests the project BIM team to ensure the following:

- The issue for construction DE models should accurately represent the design solution.
- All models should be delivered to/exchanged with MRWA in the native and/or open standard format (IFC2x3 minimum). Model IFC exports shall be run through an IFC model optimiser prior to delivery (as shown in Figure 28). IFC model optimiser is a software program that restructures and reduces IFC files.
- All design drawings and schedules should be derived from the DE model environment, where possible. All documents should be in accordance with the MRWA CAD Management Plan W81020-MPL-MN-000X.
- All models submitted should be compatible and editable (where required) within the native DE model authoring tools.
- Electronic drawing and model files should be provided in the nominated formats, enabling MRWA accessibility to these with the appropriate software.

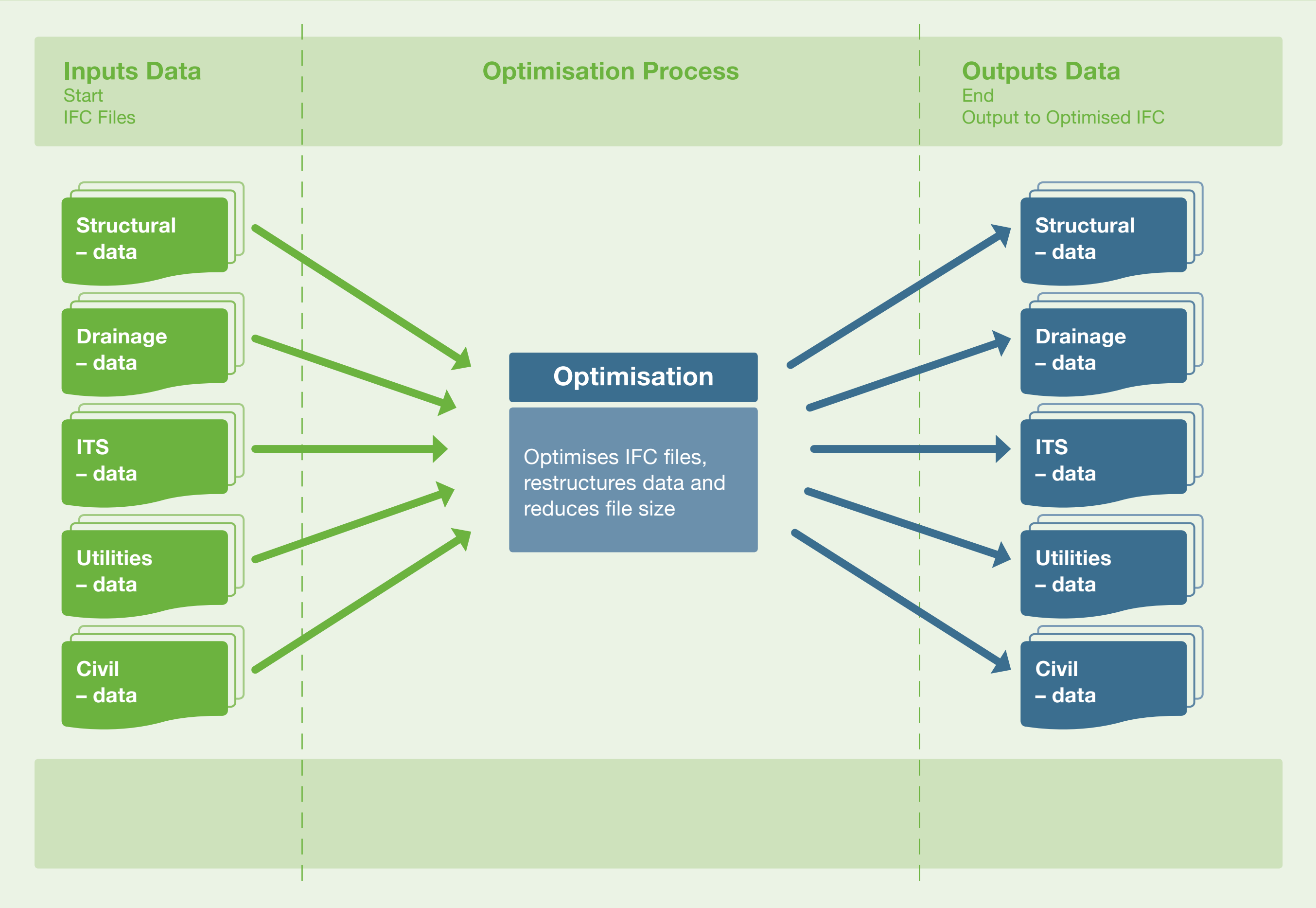


Figure 28: Industry Foundation Classes-based Data Exchange

A similar referencing system is also used in this case study for storing the road asset information, which can facilitate logical comparisons between assets and asset information by location, as well as enable assets to be located physically in the field in terms that are commonly understood and repeatable. This case uses a combination of road number, road name, carriageway, SLK and Cross Sectional Position (XSP) (if applicable), to uniquely reference where things are located on a road, similar to an address. For example, the location of a sign is uniquely referenced by the following parameters:

- Road Number: H001
- Road Name: Albany Highway
- Carriageway: Right
- SLK: 3.40km
- XSP: Median

In simplest terms, SLK (Figure 29) can be thought of as a cumulative distance along the road and is recorded in kilometres. Each road (i.e. road number) has a direction determined from lowest to highest SLK. SLK Direction in turn determines which side is designated the left carriageway and which is designated the right carriageway.

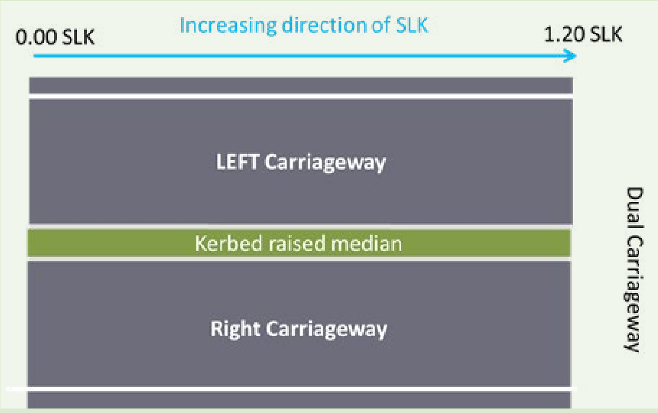


Figure 29: Straight Line Kilometre (SLK) Measurement System

XSP is used to describe the location of some types of inventory in a transverse position across the road in relation to the direction of the road according to SLK not the direction of traffic.

A simple example of this is a road sign (as shown in Figure 30). A sign has an XSP of L (Left), R (Right), M (Median) or O (Overhead). A sign therefore has an SLK that tells us its horizontal position and an XSP that tells us its transverse position.

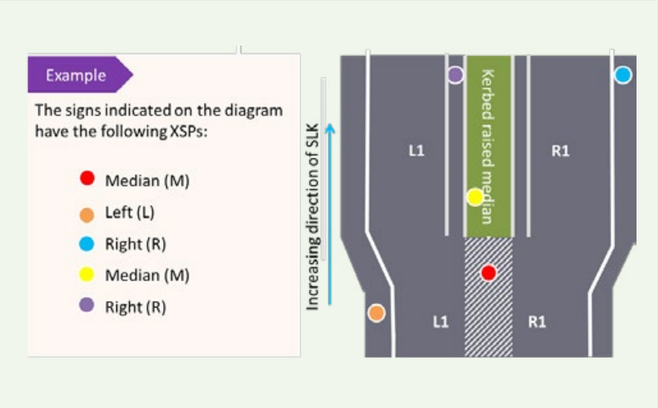


Figure 30: An Example of Using XSP Measurement System

The position and a description of all intersections on the road network are also stored in IRIS. Knowing the location of where roads intersect is important, as this location does not normally change and can therefore be used as a reference point when locating other less visible items. Intersections provide the connection between individual roads that make up the road network.

3.1.6 BIM Uses for Facilitating Digital Asset Information Management

The uses of BIM applicable to this case study project, including the scope of their application, are described in Table 3. The relevant NATSPEC National BIM Guide (NBG) clause numbers are shown. The models supplied for the civil and structural components of the design are 12dcivil design models, Tekla models and the Federated Model. The Federated Model (Navisworks) has been created for the purposes of communicating the design intent of the project as a whole and for clash detection and resolution. The 12d civil design and Tekla structural design models have been used to develop the civil and structural design, populate the drawings and provide accurate set-out data for construction.

Table 3: BIM Uses at Project Design, Construction and Completion Stages

NBG Clause No.	BIM Uses
7.1.1	**Modelling existing conditions** Create 3D Digital Terrain Model surface from survey and LiDAR information Model existing utilities and subsurface features such as geotechnical conditions (from boreholes) from available information
7.1.2	**Site analysis** Map site gradients, drainage patterns, flooding Map access and circulation patterns
7.2.1	**Civil/structural design – Spatial and Material Design model** Civil infrastructure – roadway elements, road furniture, barriers, etc. Structures – bridges (superstructure, substructure, additional models) Drainage – cross drainage culverts and longitudinal networks Electrical, communications and reticulation Utility Infrastructure – all third party Public Utility Plant infrastructure
7.2.2	**Design visualisation for communication and functional analysis** Views of the roadway elements at specific locations Coordination of horizontal and vertical alignments Sightlines for visibility to intersections, through horizontal and vertical alignment
7.3	**Engineering modelling and analysis** Use BIM software for analysis Document workflows and procedures for integration of modelling and analysis tools
7.5	**Quantity take-off and cost planning** Bulk quantity extraction from MX, 12D and Tekla
7.6.1	**Clash detection/coordination** Clash detection and coordination of models
7.7	**Facility management/as-built models** Export structures data in accordance with MRWA asset management

3.1.7 Conclusions

This Armadale Road project is still under construction. It should be noted that a significant number of benefits have already been achieved by applying BIM/DE in the project design and construction stages. Furthermore, this is the first case that Main Roads Western Australia and BIM/DE teams have invested significantly into in time and effort on delivering high-quality as-built BIM models from a road asset management perspective.

3.2 Transport Case Study 2: Forrestfield Airport Link (Perth, WA)

3.2.1 Project overview

Forrestfield-Airport Link is a passenger rail service currently under construction that will link the eastern and Perth foothill suburbs with the existing suburban heavy rail network. In April 2016, the Western Australia Public Transport Authority (PTA) awarded the design, construct and maintenance contract to Salini Impregilo-NRW Joint Venture. The rail line will provide rail services to the Perth Airport and improve the frequency of services on the Midland Line and integration with other suburban stations. It will meet existing and future public transport demand by connecting more people with more places in the eastern suburbs and its surrounds.

The Forrestfield Line (as shown in Figure 31) will integrate with Perth's existing rail network and deliver:

- an 8.5km rail extension from the Midland Line east of Bayswater to Forrestfield via Perth Airport;
- three new stations – A Redcliffe, Airport Central and Forrestfield (both with associated park-and-ride and bus transfer facilities); and
- expanded and new bus feeder services.

The new rail line will streamline the journey from Forrestfield to the CBD from up to 45 minutes by car in peak times to 20 minutes by rail, and halve the current 70-minute (peak) journey from Kalamunda to the CBD via the improved feeder bus service to Forrestfield Station (as shown in Figure 31). Services will also double in frequency from Bayswater to Daglish during the peak-hour services.

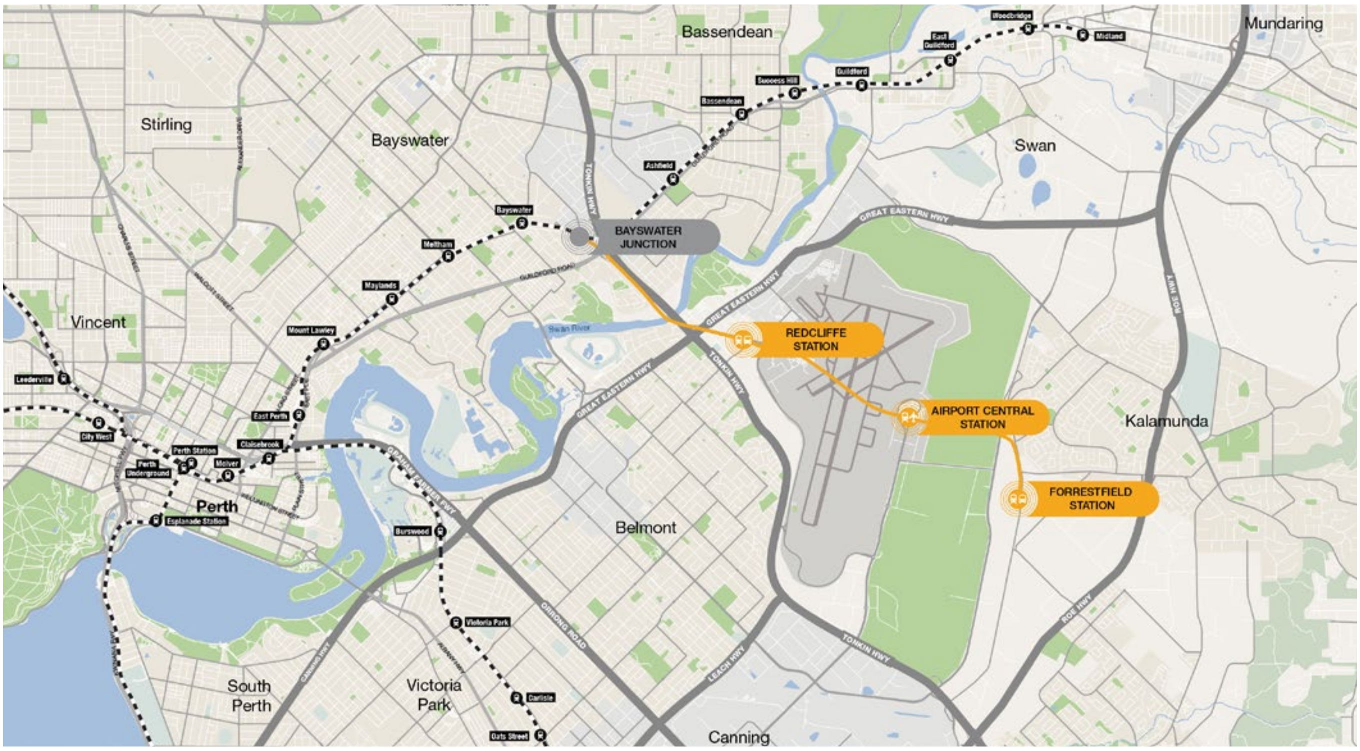


Figure 31: Forrestfield-Airport Link Plan and Location

The use of underground tunnels will reduce the project's impact on the environment and the community during both construction and operational phases. It also avoids any interference with vital aviation infrastructure at Perth Airport. The project is still under construction and will open in 2020. The construction phase started in late 2016, with site establishment at Forrestfield. A further three construction sites were established at Perth Airport, Redcliffe and Bayswater in 2017, as well as smaller sites (mainly within road reserves) for cross passages and emergency exits.

3.2.2 Asset Information Requirement

The PTA is working with the supply chain utilising digital platforms to enhance the delivery of Asset Information by, where possible, capturing data at the point of creation and in a method that enables transfer to Network and Infrastructure. The Asset Information Management Team developed a detailed asset information requirement to guide the asset information creation and updating during project design, construction, and handover stages. The contractor is required to provide (at a minimum) 30 asset details as part of the asset information submission, which includes Asset Label/Tagging, Exact Location, Sub Location, Manufacturing Details, Commissioning Data, Entry into Service data, Warranty and Defects & Liability details, etc. In addition, a series of Asset Information Templates were developed to facilitate delivery of Asset Information from the supplier to the PTA in line with the major project milestones of Finalised Design, Procurement/Construction and Commissioning. The templates have been developed in consultation with the Asset Management, Engineering and Maintenance teams to clearly articulate the detailed requirement to the supply chain.

The templates are structured to align with the PTA's Network and Infrastructures Asset Management Framework, Asset Management Plans and Asset Classification Scheme. Each template contains general and specific details relating to an asset class. The data, once transferred to Network and Infrastructure is used to support PTA's alignment with ISO55000 suite of documents and form the fundamentals of the below outputs:

- Cost reporting and forecasting;
- Performance and degradation analytics;
- Resource management requirements;
- Renewals and major overhaul/replacement strategies;
- Safe working and accessing the operating railway;
- Warranty and DLP management.

3.2.3 BIM Objective

An integral part of the delivery and one of the key stakeholder requirement is the use of Building Information Modelling (BIM) to facilitate the collation of project information in preparation of handover. To support information management as a process the use of data rich 3D modelling has been incorporated into the design and construction process to assist the design teams, builder, subcontractors and commissioning teams in reviewing design for constructability, maintainability and operability. During the design process the primary contractor was required to utilise the 3D model (Figure 32) to demonstrate compliance with PTA's requirements and in order to achieve this objective, the Contractor's scope included the below requirements:

- To create a detailed Project Information Model (as shown in Figure 33) that contains accurate and up-to-date multi-disciplinary graphical and non-graphical design information and that is progressively developed from concept through to final design and as-constructed.

Figure 32: 3D Graphical Model for the Forrestfield-Airport Link

- To provide the Public Transport Authority (PTA) and other stakeholders with the opportunity to monitor the Program of works during the project activities, including visualisation of:
  - planned (remaining) construction and installation sequencing; and
  - actual progress in construction and installation.
- Provide the PTA with a complete and accurate Asset Information Model (AIM) containing detailed information on assets and facilities and that is an accurate reflection of what has been constructed and installed.
- Provide the PTA with accurate and up-to-date information for the PTA to add to its AIM at any time during (including at the end of) the Maintenance Phase for the assets that the Contractor is responsible for maintaining.

3.2.4 Project Information Model

The Project Information Model (Figure 33) is comprised of graphical information, non-graphical information and data. All documentation produced by the project is managed in a single system providing both the PTA and supply chain access to a common data framework.

In preparation for project handover, information is being classified by a LOTS scheme under the Quality Assurance Management Plan. The LOTS scheme is designed to enable the supply chain to inform PTA that construction and commissioning tasks are complete and all related information is compiled within a LOT for PTA's review. The PTA is currently working with the joint venture representatives to coordinate the LOTS scheme content with 3D objects to better visualise project status related to information delivery.

Project Information Model

Project Information Model is a collection of graphical and non-graphical, procurement, installation, construction, commissioning, and maintenance data that encompass all assets delivered within the project.

Backup Models

"editable version of the entire Project Information Model"

- WIP and IFC native files including Revit, 12D and DWG formats.
- Fabrication models required for shop detailing.
- Temporary works design documentation and data.

Federated Models

"consolidation of all graphical and non-graphical model information from the model authors into a single up to date Project Information Model"

- Navisworks federated model from the design team which has been released periodically since first design submission.
- Navisworks integrated data from construction team once design model all submitted LOD 300.
- As-built information from survey and updated IFC models.

Assets Information Database

Compilation of data to be inputted into PTA's asset information management system for all maintainable assets on the project.

The "Asset ID" is the critcal binding string between databases.

- XLS spreadsheets from the suppliers/sub contractors utilising standard PTA asset handover templates.
- Construction Lots handover data in TeamBinder, which includes construction, procurement and installation information for each construction package. This is prepared in line with Quality Assurance procedures.
- Equipment registers generated from the PIM.
- VMT software data which includes all segment information directly from the TBM machine. Segment data will be visualised via 12D to obtained installed geometry.
- Assets Management Database, which includes all maintenance information for all maintainable assets.
- 4D Planning – integrated construction sequencing information with P6 time chainage.
- Asset Handover Templates which record asset installation, commissioning and maintenance information.

Figure 33: Project Information Model for the Forrestfield-Airport Link

3.2.5 Asset Identification

The PTA has developed a list of physical and system items that it considers ‘maintainable assets’. The development of this list has been driven by PTA Asset Managers and Asset Custodians to:

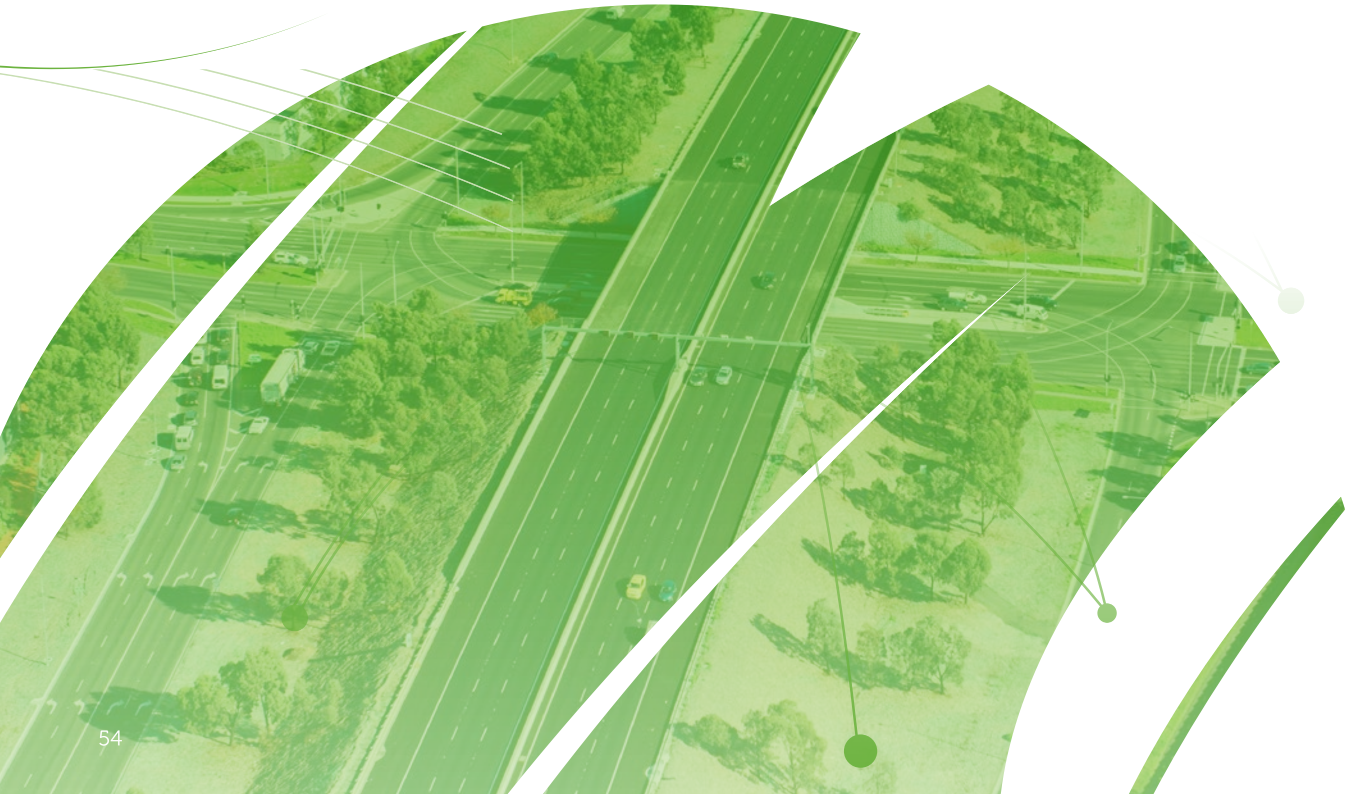
1. Know what an asset is in relation to information management;
2. Know what information to specify a project to deliver about each asset class;
3. Know why the information is required;
4. Know how to manage the information;
5. Know how to extract data and produce information when required.

To support the above requirements the PTA has developed an Asset Naming Protocol and Identification Scheme to ensure assets are consistently identified and named throughout the project stages and for asset management. Consistent naming of assets is critical to enable asset identification throughout the various systems required to operate and maintain rail infrastructure post project. PTA has applied the following rules for asset Identification:

- Must contain the information to enable an end user to clearly identify an asset;
- Must be reusable in documentation, on drawings, in models and in CMMS and SCADA systems required to manage the assets;
- Must be used as the field asset ID on nameplates and tags;
- Must be used in its complete string to be compliant with legislation;
- Must conform to PTA’s asset management framework.

3.2.6 BIM Uses for Facilitating Digital Asset Information Management

In order to assure the asset information is accurately created, maintained and transferred through project lifecycles; as a minimum, the Contractor must implement BIM at the different Project stages for the activities listed in Table 4.



Project Stages	BIM Uses	Description
Design	Design BIM Model development	Develop model based on criteria that is important to the translation of the asset's design.
	PTA equipment modelling	Any equipment provided by the PTA (e.g. ticketing machines, fare gates) must be included in the model with all characteristics and to the same quality and detail as the rest of the required model.
	Asset Maintenance Information template updates	Add data specified in asset maintenance templates as required in design stages.
Construction	BIM Construction Model development	Continuously update the Project Information Model throughout the construction phase as each design discipline achieves Final Design. The Contractor must share the fully editable Project Information Model with its subcontractors. Subcontractors must develop IFC and shop drawings using the Project Information Model and provide design details to the Contractor in order to maintain a single up-to-date Project Information Model. As-constructed and as-installed information must be fed back into the Project Information Model.
	Model auditing	Verify asset attribute data into model.
	Asset Maintenance Information template updates	Add data specified in asset maintenance templates as required in construction stage.
Prior to the date of practical completion	As-built BIM Model development	Capture all installed conditions during construction.
	Asset Maintenance Information template updates	Add data specified in asset maintenance templates as required for this stage as well as any further information required to complete each template.
	Contractor asset maintenance	Integrate BIM model data with existing Enterprise Asset Management System (Ellipse for future replacement) or an asset maintenance system of the Contractor's choosing in preparation to use of this system for all maintenance activities required of the Contractor.
	Support commissioning and practical completion	Provide all information required for commissioning and Practical Completion to the PTA in electronic format within the final Project Information Model. Verification procedures must be developed by the Contractor in its BIM Management Plan to allow documentation to be electronically provided to the PTA.
After the date of practical completion	Transition from Project Information Model to AIM	Contractor is responsible for updating and maintaining the Project Information Model and meeting all Scope of Works and Technical Criteria requirements until Practical Completion. At Practical Completion, the Project Information Model will become the AIM and will be updated and maintained by the PTA. Between the date of Practical Completion and Final Handover, the Contractor is responsible for providing the PTA with all maintenance intervention and configuration information in a format compatible with the Asset Information Model (AIM).
	Asset management information	Between the date of Practical Completion and Final Handover, the Contractor must submit all information related to inspection and maintenance works that it carries out to the PTA in an electronic format that is compatible with the PTA's AIM. The Contractor must provide sufficient information to the PTA to allow the AIM to be fully up to date at Final Handover.
	Defects correction period	Visually identify defects that must be rectified by the Contractor and update the AIM as defects are verified by the PTA as complete.

Table 4: BIM Uses at Project Design, Construction and Completion Stages

3.2.7 Conclusions

This case study project is still under construction. Currently, the requirements for delivery of asset information have been clearly defined from the perspective of organisation and their asset managers. BIM was successfully used at project design and construction stages to improve asset information capturing and handover. Four levels of detail (i.e. LOD 100-400) were defined to quantify the information attached to BIM models or objects. In addition, at the end of each project stage, compliance checking was conducted to assure all asset data was collected as required. However, how to automatically transform or link the as-built BIM data to the existing Public Transport Authority, Western Australia's asset management systems has not yet been realised.

Lessons learned from this case include: (1) asset information requirement should be defined at the earliest stage of the project; (2) the client's asset management team should take the lead of developing asset information requirement and asset information delivery process; (3) a unified asset hierarchy system should be developed to record physical rail assets in a set of logical groupings and sub-groupings, and allow for aggregated and detailed analysis of asset performance at various levels, from the facility level down to the individual equipment item level; and (4) a collaborative working environment should be encouraged to facilitate implementation of new technologies.

The Sustainable Built Environment National Research Centre (SBEnrc) industry research team is keen to continue working with Public Transport Authority, Western Australia to develop this case study further to support the railway operation and maintenance.

3.3 Transport Case Study 3: New Grafton Bridge (Grafton, NSW)

3.3.1 Project overview

The New South Wales Government is funding this A$240 million project which involves building an additional 525 metre bridge 70 metres downstream from the existing road and rail bridge on the Clarence River in Grafton (Figure 34 and Figure 35). The project also includes upgrading parts of the road network in Grafton and South Grafton to connect the new bridge to the existing road network. The new bridge will consist of two lanes but has been designed to be increased to four lanes when traffic levels require it. The existing bridge will remain in use, but with a weight restriction for heavy vehicles. New South Wales Roads and Maritime Services (RMS) is the project client while Aurecon is the structure designer with Fulton Hogan serving as the construction contractor.

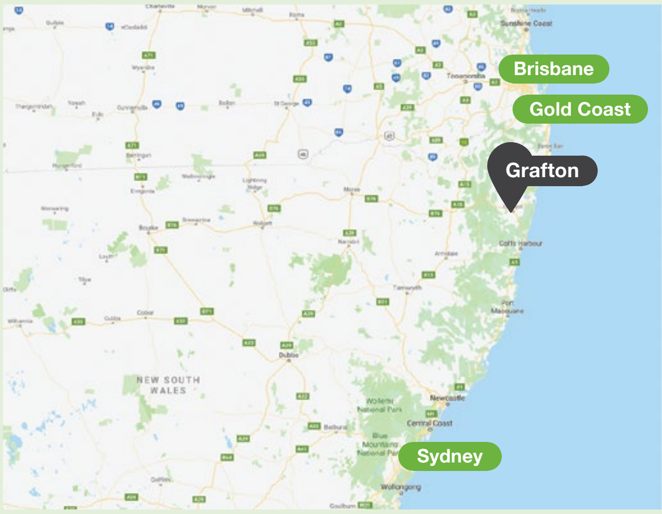


Figure 34: Location of the New Grafton Bridge

Figure 35: Placement of the New Grafton Bridge

3.3.2 Flood Simulation and Building Information Modelling (BIM)-based Bridge Design Optimisation

The town of Grafton is subject to flooding. The current river levee system (as shown in Figure 36) provides protection from a 1 in 20-year flood event and a key objective for the project is to minimise the flood impact of the new bridge while maintaining the existing level of flood immunity for Grafton and South Grafton. RMS, through detailed field investigations and changes to the bridge design, has reduced the upstream water increase due to the new bridge from 90mm to only 30mm. This reduction has been achieved in a number of ways.

Detailed river bed surveys (as shown in Figure 37) were carried out in 2015 to measure the depth of the river. The last survey of this type was in 1963 and this helped the project understand the changes to the riverbed over time. Eleven kilometres of the levee system were also surveyed to map the elevations and identify low sections.

The biggest influence was through innovations to the bridge design by Aurecon. The concept design developed for the Environmental Impact Assessment had a bridge pier requiring eight piles (as shown in Figure 38). In order to minimise the flood impact of the new bridge, BIM technology was used to optimise the bridge design especially in reducing the pile numbers. Figure 39 shows the new pier design after optimisation. Improvements to the design have streamlined the pier shape, requiring only two large piles. This change allows water to flow around them more efficiently.

In order to offset the remaining small water level increase, RMS has been consulting with the community, council and the State Emergency Services (SES) to carry out work to the levee system. This will include re-levelling the low points to a minimum height to maintain the current level of flood protection. In a few cases where this is not possible, the Project team is working with property and business owners to find individual solutions to reduce this impact. While there will be a slight increase in upstream river levels, there will be no rise in water levels downstream of the bridge. The new bridge will bring many benefits to the residents of Grafton and South Grafton. Aurecon's innovative design for the bridge, and the flood modelling done as part of the project, ensures the community will enjoy these benefits with no additional flood risks.

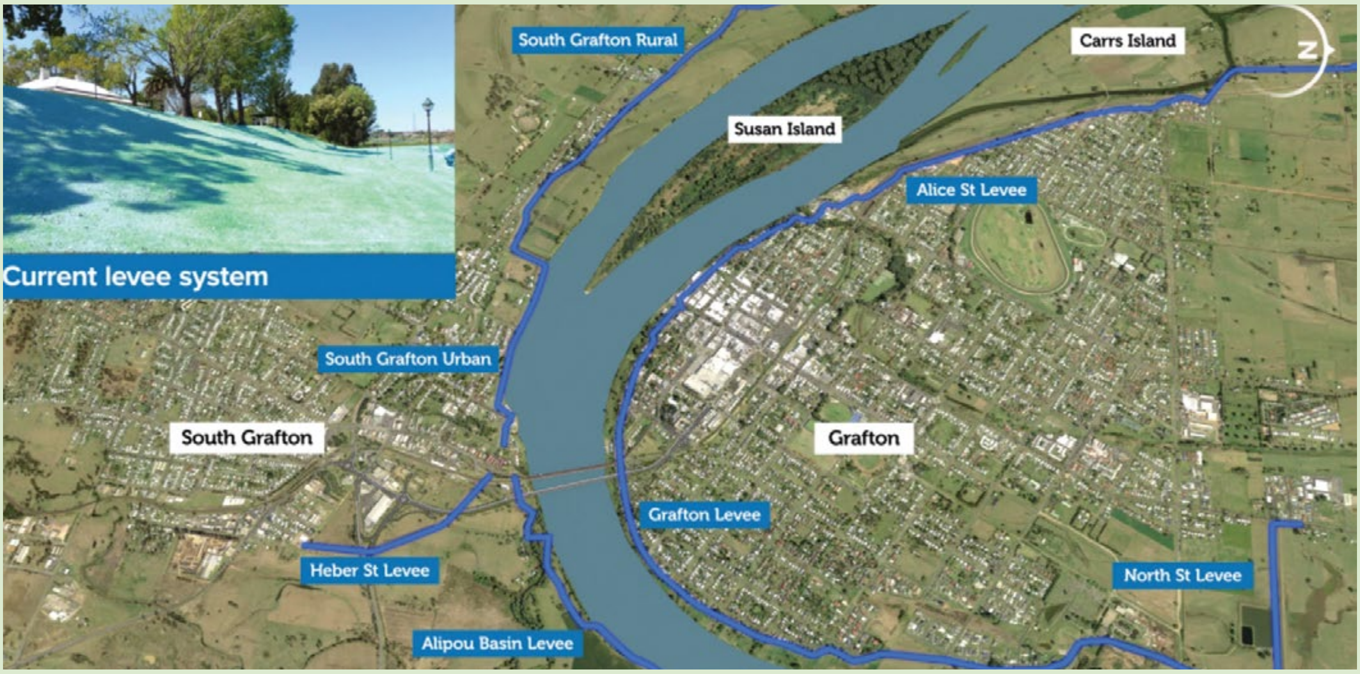


Figure 36: Current Grafton and South Grafton Levee System

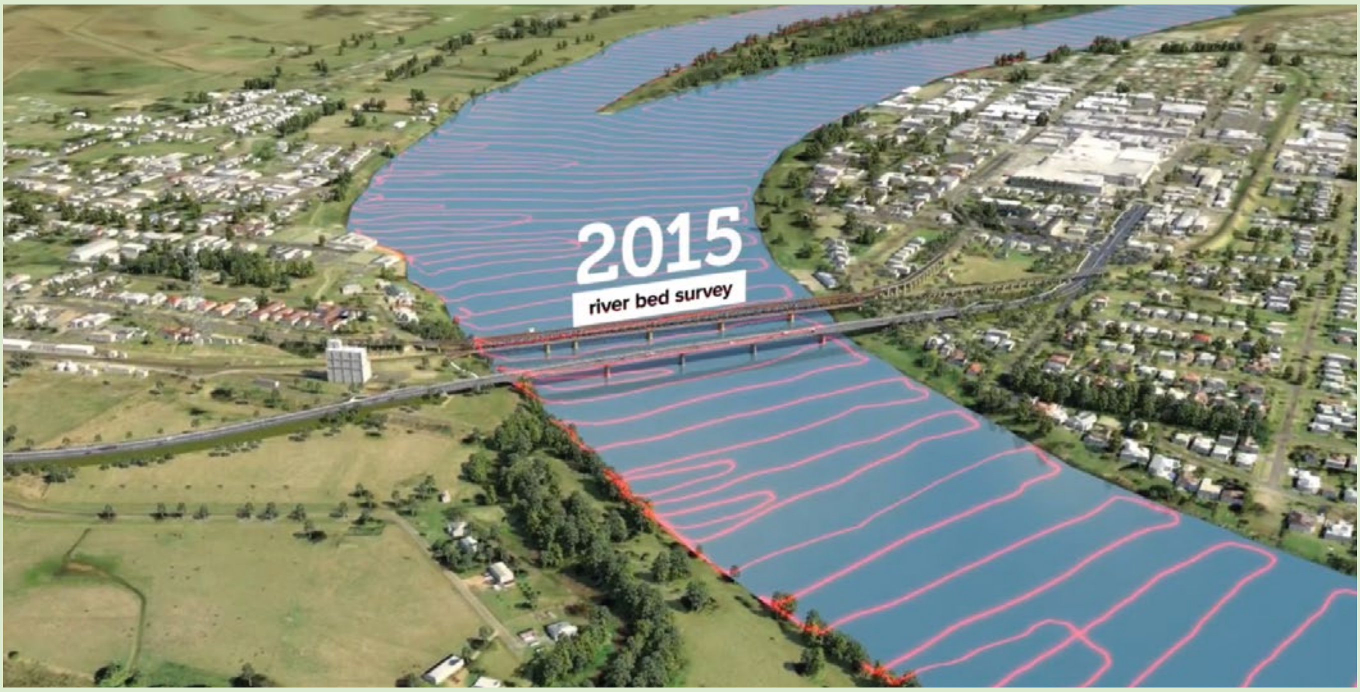


Figure 37: River Bed Survey

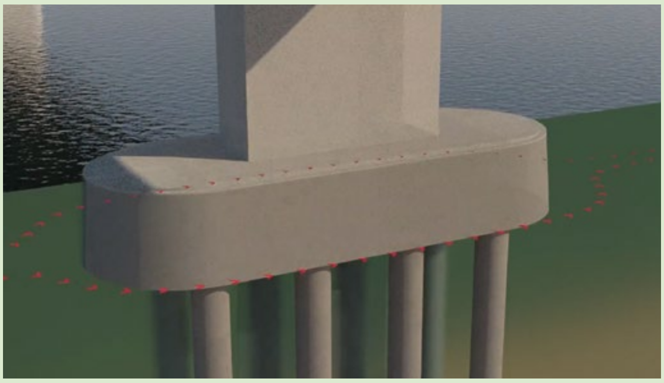


Figure 38: Bridge Pier Design with Eight Piles (Before Optimisation)

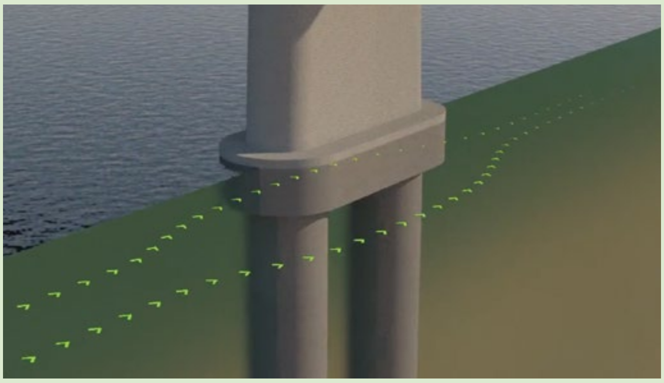


Figure 39: Bridge Pier Design with Two Large Piles (After Optimisation)

3.3.3 BIM-based Bridge Construction Simulation

In this case study, BIM was also used to simulate construction processes. The objective is to build the structure virtually before it is actually constructed. This is an order of magnitude more complex, but it is a very valuable undertaking as described below.

The construction sequence of a modern bridge is of great interest to both designers and builders. For major bridges, it is important that the designer establish the feasibility of the construction sequence carefully. This includes substructure construction, including cofferdams, pile installation sequence, and pile-cap and pier construction. The superstructure erection schemes can be extremely complex and challenging. A Virtual Construction (4D) simulation (linking the 3D model with time or schedule-related information) of the erection sequence (as shown in Figure 40 and Figure 41) can be invaluable in refining the construction procedure; that is, making it more rational, efficient and constructible, thereby enabling the engineer to produce a more competitive design.

The construction sequence is coupled with the all-important variable: time. The simulation can be controlled to run in accordance with the construction schedule, highlighting construction operations on the critical path.

Using the simulation model, the engineer can experiment with different construction sequences, selecting the fastest and most efficient method to be implemented in the field. This can translate into real and significant savings on a construction job.

3.3.4 Conclusions and Future Works

This Grafton Bridge project is still under construction. In the future, the SBEnrc research team will work with NSW Government and designer Aurecon to enrich the 3D Bridge Information Model so that it can be continually used to support the bridge operation and maintenance. The enrichment work will be conducted according to the proposed Digital Asset Information Model requirement. Firstly, 3D objects within the Bridge Information Model will be re-classified and coded based on an open and widely-used Bridge Asset Classification System (refer to this project's detailed Research Report). Then, new attributes will be added to each 3D object according to the predefined Asset Information Requirement. Thirdly, the 3D-enriched Bridge Model will be integrated with a GIS. Finally, an open data exchange standards-based plugin will be developed to automatically transfer the information within the 3D Bridge Model to RMS's Asset Management Platform.

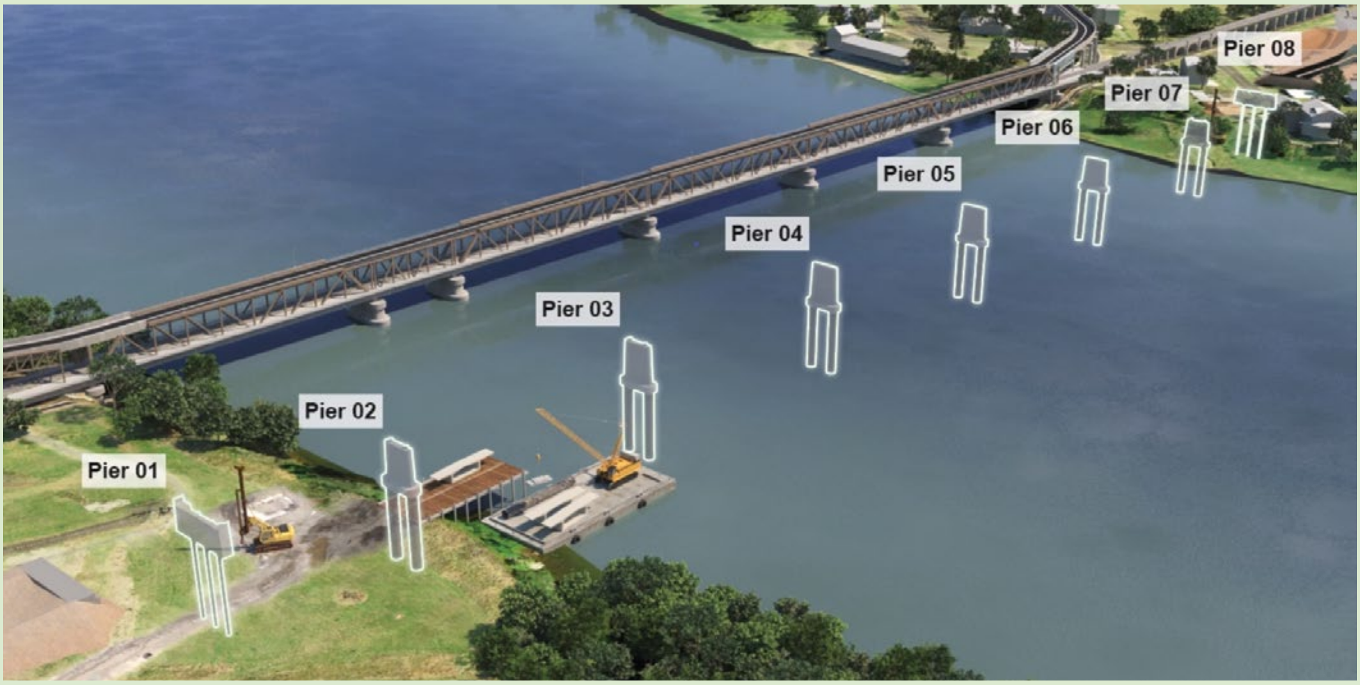


Figure 40: Virtual Construction (4D) Simulation for Pier Installation

Figure 41: Virtual Construction (4D) Simulation for Segment Lifting and Installation

3.4 Transport Case Study 4: Digital Asset Information Management in VicRoads (VIC)

3.4.1 Project overview

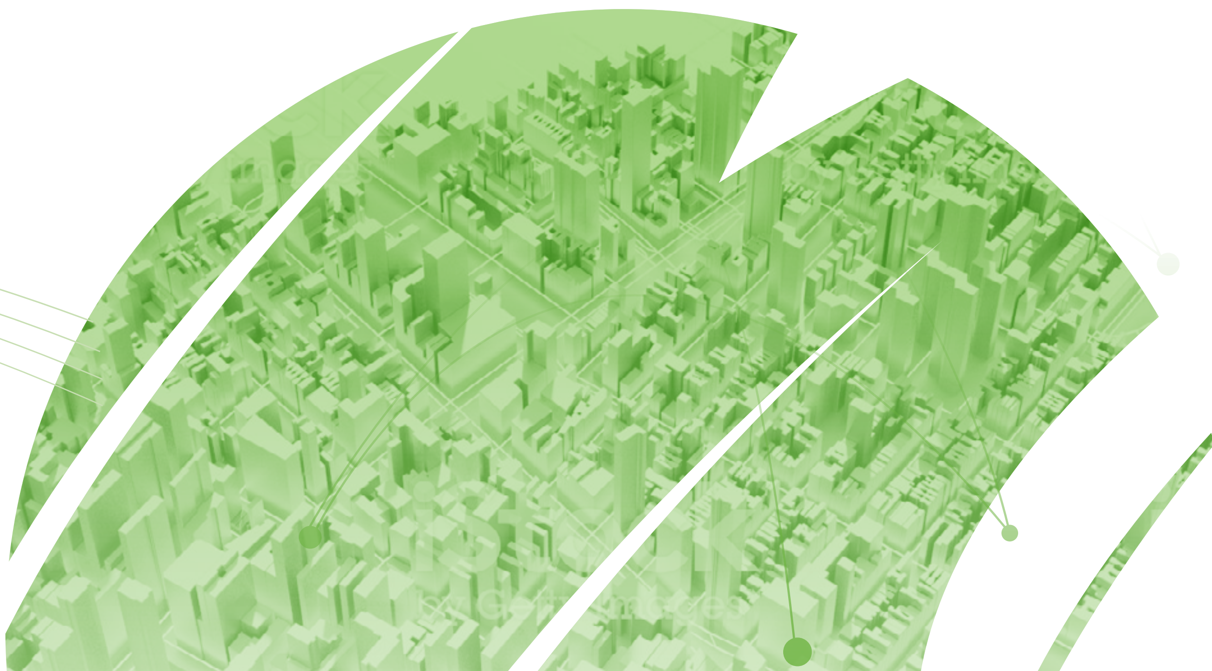
VicRoads is the Victorian Government's central road agency. Its purpose is to deliver social, economic and environmental benefits to communities throughout Victoria by managing the Victorian arterial road network and its use as an integral part of the overall transport system.

The aim of this case study was to: (1) understand VicRoads' current road asset operation and maintenance processes; (2) understand VicRoads' current asset management tools or platforms including their functions, data inputs and outputs, and underlying data schemas; and (3) benchmark VicRoads' road asset management practice in terms of digitalisation.

Document reviews and internal interviews and workshops were conducted to help the team understand VicRoads' current asset management practices.

Collected documents included:

- VicRoads organisation chart
- Design and construction specifications
- Asset management documents:
  - Pavement
  - Street lighting
  - Intelligent traffic system
  - Bridges
- Road design publications and standards



Reviewed asset management tools and/or platforms included:

- vMap
- RAI: Road Asset Inventory system
- SCATS (Sydney Coordinated Adaptive Traffic System): an adaptive urban traffic management system that synchronises traffic signals to optimise traffic flow across a whole city, region or corridor
- STREAMS: an international award-winning Intelligent Transport System (ITS) that supports road authorities to help save lives, reduce congestion and make road networks safer
- AMCS (Asset Monitoring and Control System): a street lighting management system for electrical assets
- Connect: Financial System (formerly known as PARMS)
- RAS (Road Asset System): system for managing structural assets (bridges, gantries, noise walls etc.), including locations information and inspection reports
- Spreadsheets across various regions to document and manage most other road related assets, including pavements, drainage, traffic barriers, road side vegetation and furniture

Interviews and workshops held with VicRoads' departments included:

- VicRoads' Smart Journey Systems, Asset Management Team (ITS Asset Management)
- VicRoads' Smart Journey Systems, Delivery team (ITS Project Delivery)
- Network Design Services Team (VicRoads In-house Design)
- Asset Services (Corporate Asset Management)

Five main findings were identified:

- The data schemas used by the current asset management tools/platforms are various in terms of asset location referencing and asset hierarchy systems;
- The asset data handover process is document-driven which is time-consuming, labour-intensive and prone to human errors;
- Digital Engineering and BIM technologies are rarely applied;
- There is a lack of well-defined processes for asset data quality checking and assurance; and
- The Asset Information Requirement for each discrete or individual asset management tool/platform (i.e. RAI, SCATS, STREAMS and AMCS) is well-defined. However, there is not an integrated Asset Information Requirement developed which considers these various requirements and integrates for efficiency.

3.4.2 Digital Asset Information Management in VicRoads: Current Practices

3.4.2.1 Asset Classification/Hierarchy Systems

In 2018, VicRoads developed a new Asset Hierarchy in order to meet the requirements of the new enterprise asset management system version (i.e. Ellipse 6.3) whilst still supporting the essential processes of existing Connect system (formerly known as PARMS-Program and Resource Management System). The new Asset Hierarchy contains three main types of sub-hierarchies: Road Asset Hierarchy, Structures Asset Hierarchy and Electrical/Communications Asset Hierarchy.

Figure 42 shows an example of the Road Asset Hierarchy. The new Hierarchy recognises the existing equipment classes in Connect and allows for the creation of additional records to support assets to be transferred from legacy systems. However, the new Asset Hierarchy can only be maintained, modified and extended by authorised asset managers using standard Connect user functions, which means it cannot be shared and used by other internal Asset Management Tools such as RAI, SCATS, STREAMS and AMCS. Indeed, each tool has its own asset hierarchy to support asset information storage. Therefore, VicRoads Asset Management team needs to maintain at least five different types of asset hierarchies. The lack of a unified Asset Hierarchy increases the difficulty and complexity of asset information capturing, updating and validation. In addition, automated asset data sharing and exchanging among the various asset management systems and platforms becomes impossible.

3.4.2.2 Asset Location Referencing

Currently, the Asset Location Referencing used is the VicRoads' Standard Road Referencing System (SRRS), which comprises a database model of the declared road network, defined by links joining physical reference markers and fixed features of known and measured locations. The location of any point on the network may then be defined by measured distances along the link relative to a physical reference marker or fixed feature.

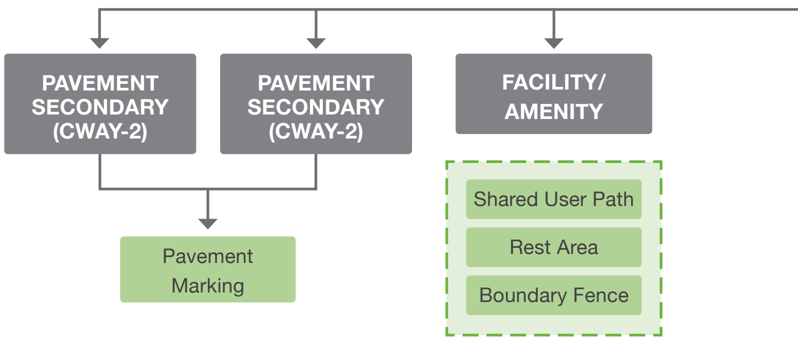
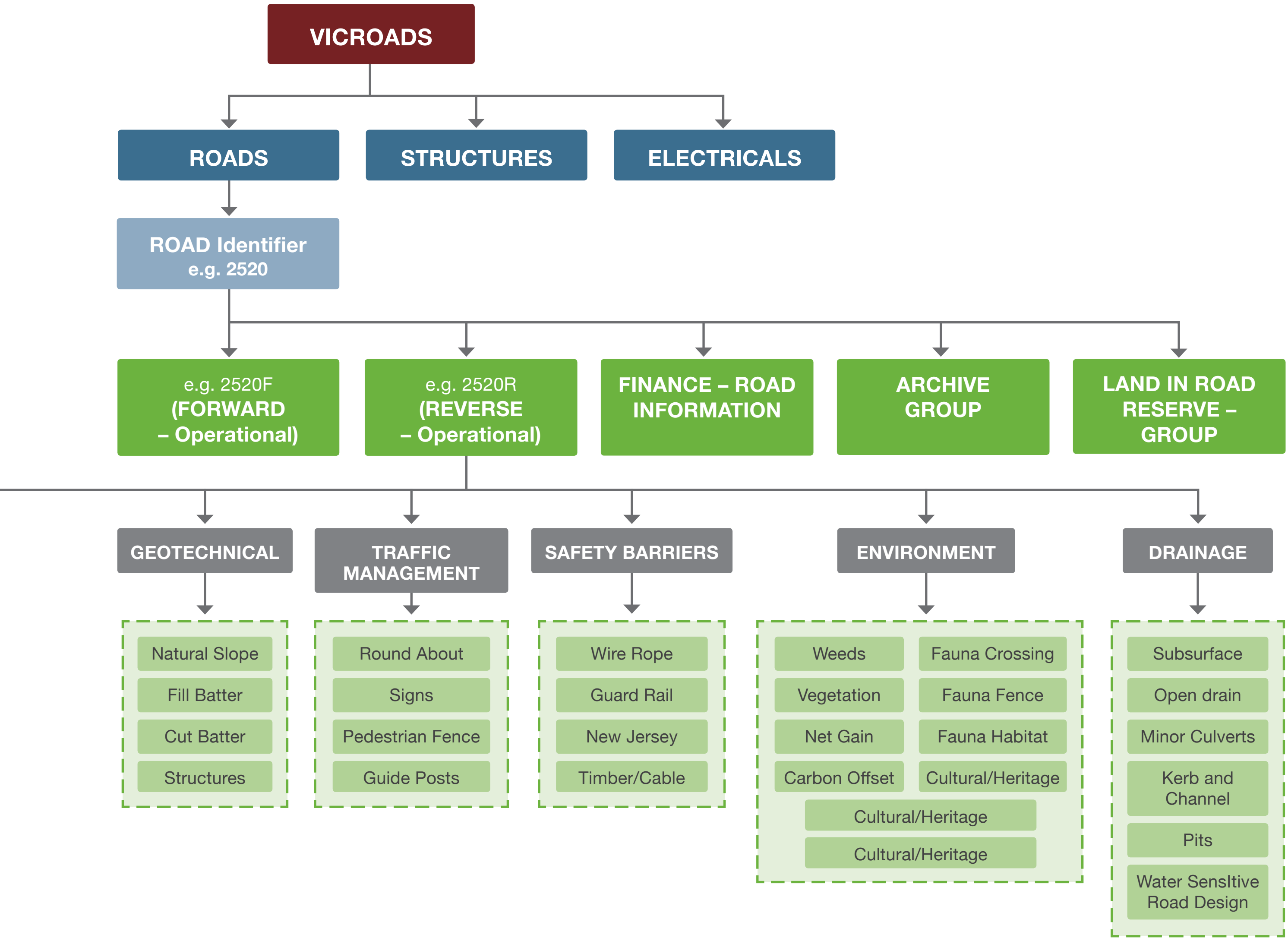


Figure 42: Road Asset Hierarchy

The SRRS is a linear referencing method which can be communicated concisely via plaintext. However, a major limitation of linear referencing is that specifying points that are not on a linear feature is troublesome and error-prone, though not entirely impossible. Consider for example a ski lodge located 100 meters to the right of the road, traveling north. The linear referencing system can be extended by specifying a lateral offset, but the absolute location (i.e. coordinates) of the lodge cannot be determined unless coordinates are specified for the road; that process is



prone to error particularly on curved roads. Another major drawback of linear referencing is that a modification in the alignment of a road (e.g. constructing a bypass around a town) changes the measurements that reference all downstream points. The system requires an extensive network of reference stations and constant maintenance. In an era of mobile maps and GPS, this significant maintenance overhead for a linear referencing system challenges its long-term viability and acceptability.

3.4.2.3 Asset Management Tools and Platforms

In VicRoads, six main systems and/or tools are currently utilised to support asset operation and maintenance: RAI, SCATS, STREAMS, AMCS, RAS and spreadsheets for structures and road assets.

RAI is a powerful system, providing fast and efficient filtering and searching utilities, enabling staff members to easily locate asset records. RAI provides the ability for VicRoads to:

- record inventory information regarding electrical, communications, operating systems;
- associate incident and traffic management, and traffic control assets for the full lifecycle of the asset;
- record and track maintenance jobs for each asset;
- record and track jobs relating to faults for each asset and their rectification;
- allocate to, and notify contractors of, jobs for their attention; and
- produce various reports on the assets and jobs.

SCATS is an adaptive urban traffic management system that synchronises traffic signals to optimise traffic flow across a whole city, region or corridor. SCATS is more than just a way of linking traffic signals to provide road management coordination; it is a sophisticated traffic engineering system that allows implementation of complex, objective-oriented, traffic management strategies.

STREAMS is an international Intelligent Transport System (ITS) that supports road authorities to help save lives, reduce congestion and make road networks safer. It enables road authorities to manage their transport network holistically, rather than as a collection of separate components. The unique software architecture provides a complete, integrated ITS platform supporting a comprehensive range of services and infrastructure, making it possible to manage traffic signalling, incident response, motorway management and other traffic services from a single system. This is one unique capability that sets STREAMS apart from other systems.

AMCS is a smart street lighting management system that improves safety and security through improved visibility, saves money by consuming less electricity and has a positive impact on the environment due to the increased life expectancy of LED luminaires.

It should be noted that these four systems normally work independently. Although there are a few connections built between RAI and SCATS, data searching and sharing across these four systems are difficult and time-consuming. Currently, VicRoads is developing a new platform, vMap, to address this issue. vMap is a one-stop-shop for all spatial data. It contains information from a variety of different data sources around VicRoads including assets, road networks, strategic and planning data, and road safety.

3.4.2.4 Asset Transformation Project

In 2016, the Department of Treasury and Finance mandated all Victorian Government agencies to create a consistent and transparent enterprise-wide methodology to manage their asset related activities throughout the lifecycle of each asset type.

VicRoads is now required to complete an analysis of all asset-related activities annually and to compare the data with up to 47 Asset Management Accountability Framework (AMAF) Requirements. This is known as 'Attestation'. This process will also assist VicRoads to address findings from the Victorian Auditor-General's 2017 report, 'Maintaining State-Controlled Roadways', and be ready for two further audits in 2018.

3.4.3 Digital Asset Information Management in VicRoads: Benchmarking

Figure 43 summarises a framework developed in SBEnrc Project 2.51 for a Digital Asset Information Model for transport infrastructure, which includes four main modules: (1) Asset Information Requirement; (2) Asset Classification System; (3) Asset Location Referencing System; and (4) Open BIM-GIS Data Exchange Standards. It should be noted that these four modules are inter-linked with one another. Detailed explanation of these can be found in Project 2.51's detailed Research Report. For projects without BIM/GIS implementation, the first three modules should be interlinked with each other to improve asset data searching and updating. For projects with BIM/GIS implementation, the first three modules should be linked/incorporated into the BIM-GIS platform. This case study uses the model in Figure 43 (i.e. the future or ideal state) to benchmark the current asset management performance of VicRoads.

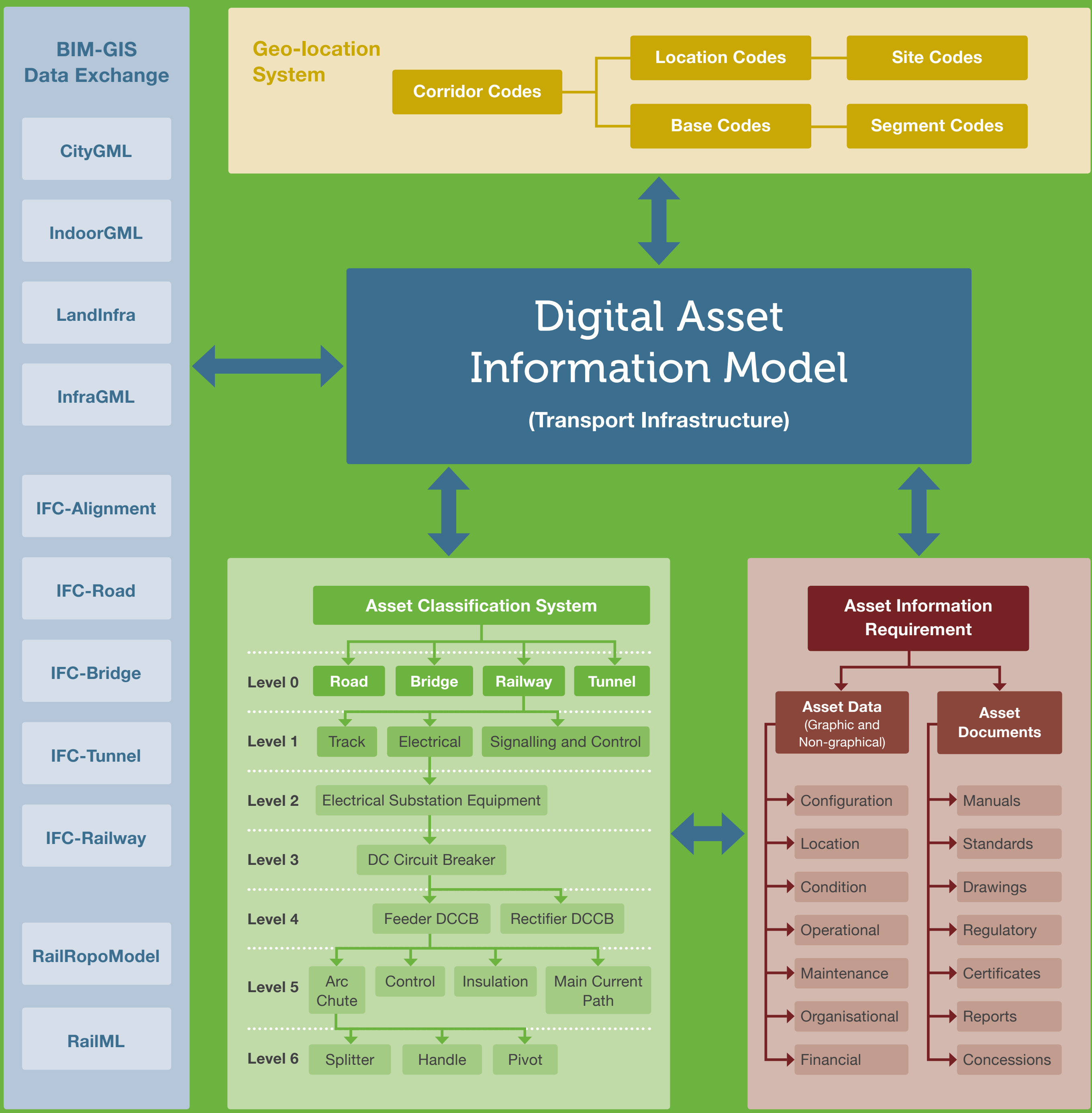


Figure 43: Framework for the Digital Asset Information Model for Transport Infrastructure

Benchmarking

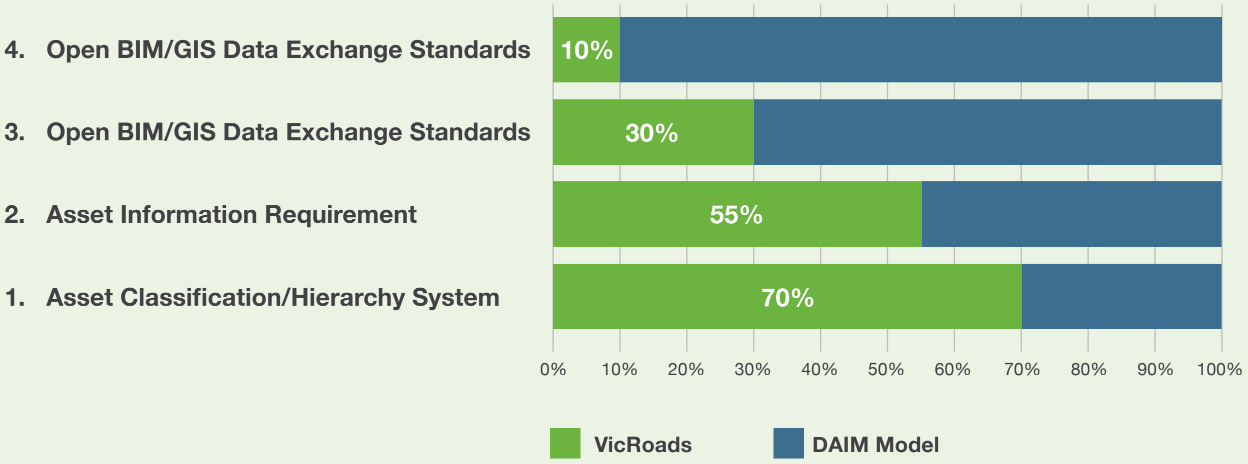
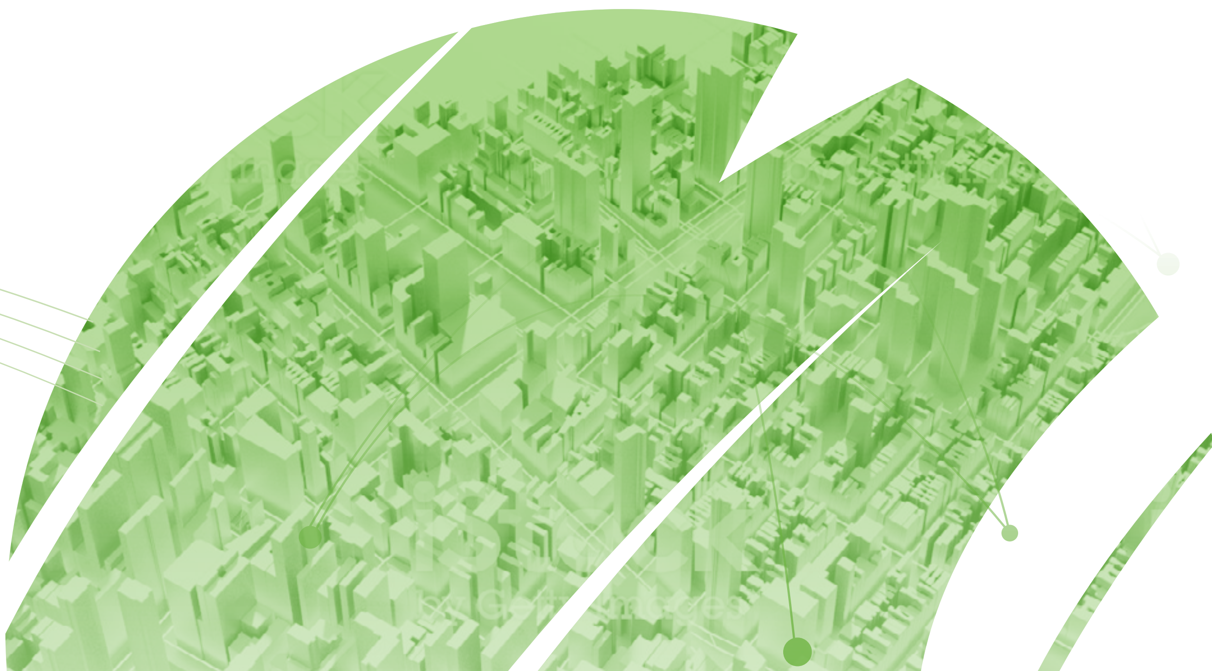


Figure 44: Benchmarking Study – VicRoads Practice Compared to the DAIM Model

Figure 44 illustrates the benchmarking performance results (as a percentage of the ideal) according to the collected documents and interview records from VicRoads. They are all far from the requirements of the ideal model, especially the aspects of Asset Location Referencing and Open BIM/GIS Data Exchange Standards.



3.4.4 Conclusions and Recommendations for the Future

As a result of the benchmarking activity, three early recommendations are proposed to facilitate the transformation from VicRoads' current asset management practice towards the ideal DAIM paradigm.

Recommendation 1: *Develop a unified Asset Classification/Hierarchy System and apply it to all the internal asset management systems/platforms.*

The aim of the unified Asset Classification/Hierarchy System is to provide a single point of reference of asset discipline, asset class, asset function, asset type and asset component for stakeholders involved in the planning, acquisition, operation, maintenance and disposal of assets. Four existing Asset Classification/Hierarchy Systems, developed by Transport for NSW, NSW Roads and Maritime Services, Austroads and One Network Road Classification (ONRC), can be used as a basis. Each of them has been explained in detail in this project's final Research Report.

Recommendation 2: *Move from a Linear Referencing System (i.e. 1D) to a Spatial Referencing System (i.e. 2D or 3D).*

Given the limitations of the Linear Referencing System, Spatial Referencing Systems such as Geospatial Referencing Systems (2D) and Geometric Referencing Systems (2D or 3D) should be applied. The former one provides a way to describe locations on the earth's surface in real-world coordinates. This includes GIS as well as coordinate-based mapping systems. Searching and mapping are two key advantages of this referencing system. Most governments rely heavily on GIS applications for managing geographic data. These provide searching (proximity-based) and modelling abilities. The latter is based on digital models that provide coordinate geometry within local model coordinates. Typically, these include digital design (2D or 3D) and BIM models. Some model environments are stand-alone and, more recently, they may be geo-connected (placed in the real world). The family of geometric reference systems are those based on geometric models of infrastructure.

Recommendation 3: *Apply BIM and other Digital Engineering technologies in future projects.*

Digital Engineering or BIM, is much more than developing static models. It can facilitate harnessing the true potential of the built environment industry and creating a platform for multiple applications by integrating digitisation and GIS. In addition, as-built BIM models can accelerate the information handover phase and improve asset data quality in terms of accuracy, integrity and consistency. BIM processes are now mainstream to both new buildings and infrastructure and have great value in retrofit and refurbishment projects where complimentary technologies such as laser survey techniques and rapid energy analysis are employed. Over the next decade, BIM and Digital Engineering technologies will combine with the internet of things (providing sensors and other information), advanced data analytics and the digital economy to enable asset owners to plan new infrastructure more effectively, build it at lower cost and operate and maintain it more efficiently.

4. Conclusions

The Sustainable Built Environment National Research Centre (SBEnrc) research team worked with its Australian industry partners to select ten case studies to examine asset management processes in the housing, building and transport infrastructure sectors.

Through the P2.51 project, the team focused on a comprehensive review of digital asset management practices, including asset data exchange, asset classification, asset location referencing and asset information requirements. The case studies were used to pinpoint issues in identifying the information needed to understand the use of BIM for asset management, ways of improving the use of BIM-based technology to support asset management and the changes needed in industry processes to make this more efficient.

The cases analysed illustrated that the use of BIM/Digital Engineering can improve asset management processes and outcomes over the facility lifecycle. The value in improving these processes is enhanced if the client's management team take the lead in developing information requirements and asset information delivery processes. Defining asset information requirements at the earliest stage in a construction project and consistently at an organisational level can help more fully capture the whole-of-life value delivered by digital asset information management.

The accompanying document *Digital Asset Information Management: A Guide and Manual* provides specific recommendations arising from this research-into-practice initiative, intended to facilitate the changes needed for industry to make the uptake of digital asset information management processes more efficient. Together with this Case Studies report, the Guide and Manual will aid in the wider adoption and consistent curation of digital information for maintaining and operating assets across the built environment supply chain, thereby improving the efficiency of managing community assets, returns on investment and the sustainability, resilience and safety of assets.

Sustainable Built Environment National Research Centre

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