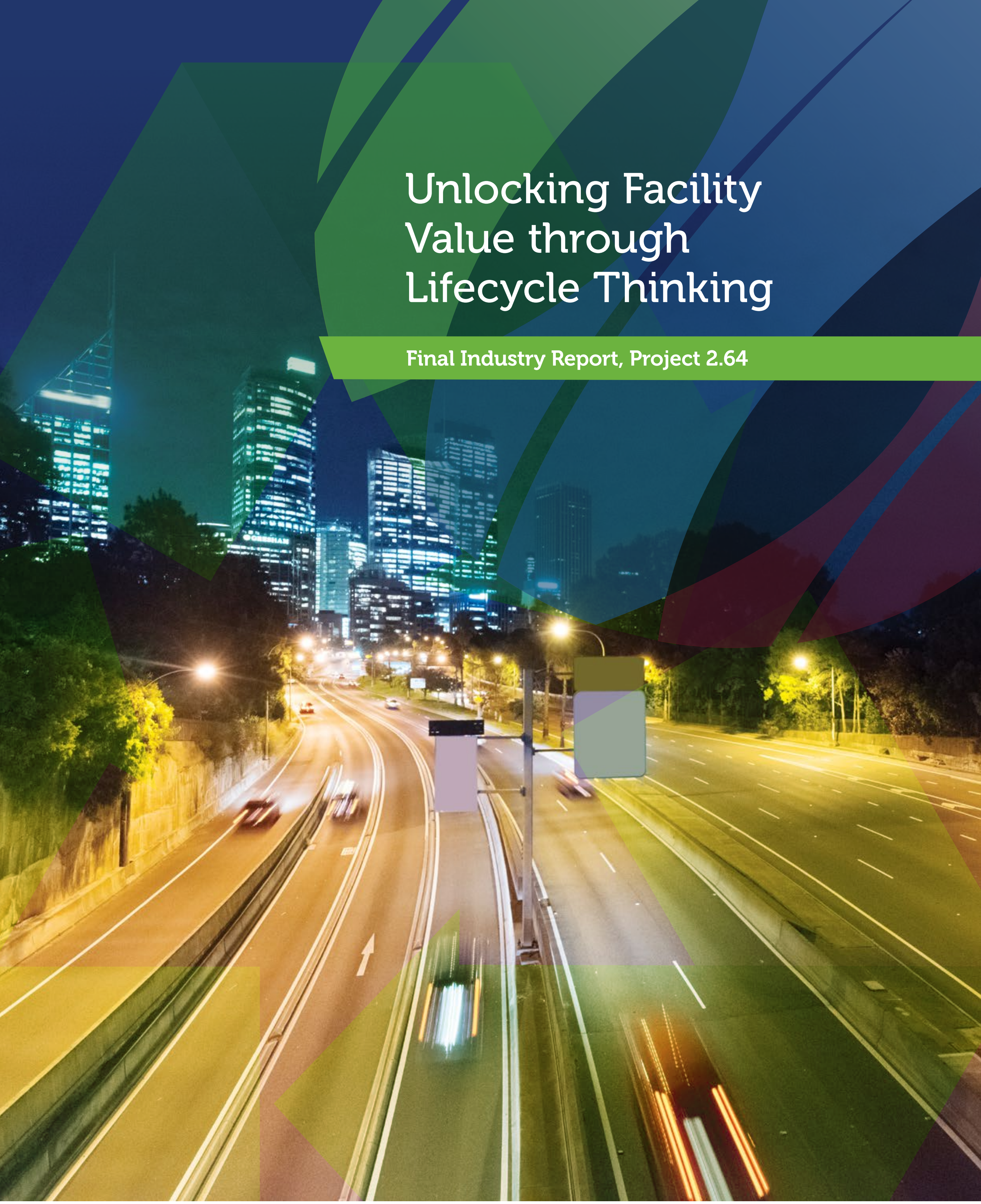
Unlocking Facility Value through Lifecycle Thinking

Final Industry Report, Project 2.64



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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 organisation. By working together, we can transform our industry and communities through enhanced and sustainable business processes, environmental performance, and productivity.

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Executive summary

Lifecycle thinking has been increasingly recognised as an effective approach to evaluate the impact of decisions over a project's lifecycle. It intends to go beyond the traditional focus on manufacturing and construction to include the entire lifecycle of projects including manufacturing, transportation, construction, operation, maintenance and rehabilitation, as well as end-of-life treatment as the basis for economic, social and environmental evaluation.

While lifecycle thinking is promoted in the housing, building and infrastructure sectors, its implementation faces many challenges, including the long life span of the operation stage and the development of appropriate platforms for managing the lifecycle asset information. Recent developments in innovative technologies – including building information modelling (BIM), sensing and tracking and image processing – provide opportunities to tackle such issues. The integration of these innovative technologies and approaches to enable lifecycle thinking to realise facility value has therefore been attracting much attention in recent years.

The objectives of this research project include:

- addressing the industry challenge of investigating digital platforms throughout the facility lifecycle for making decisions that suit the overall duration of the lifecycle
- identifying the role of artificial intelligence to models through the various lifecycle phases of planning, design, construction and asset management to better understand and visualise the impacts of decisions undertaken
- facilitating avenues of education for industry and the broader community on the needs and methods of lifecycle thinking, not only for the purpose of a project's planning and delivery, but also for the operation and maintenance phases of facilities in unlocking their value.

It is expected that outputs can be implemented to assist the integration of innovative technologies and approaches, and these include BIM, machine learning and whole-of-life costing into lifecycle thinking for the effective lifecycle management of building, housing and infrastructure projects.

Introduction

There is an expectation in Australia that the building, housing and infrastructure sectors must support a high quality of living; however, this cannot be achieved if the building, housing and infrastructure networks and systems are not appropriately managed.

Lifecycle thinking is defined as going beyond the traditional focus on manufacturing to focusing on the entire lifecycle of products/facilities. This approach has been advocated in building, housing and infrastructure projects. For example, the most commonly adopted lifecycle costing approach, or whole-of-life cost approach, to quantify the total cost of building, housing and infrastructure projects has been developed and implemented in these sectors for many years. Including the economic, social and environmental impacts of a project over its lifecycle is beneficial because these impacts consider both the immediate and long-term benefit and cost of the project. Their inclusion for consideration in such an approach can provide a comprehensive understanding of the potential impacts of decisions.

Technology plays a vital role in achieving the value of facilities. Building information modelling (BIM) is recognised as an emerging technology which can help the building, housing and infrastructure sectors to transform towards a digital environment. By adopting the latest sensing, tracking and data-capturing technologies, the volume of data increases, requiring advanced data analysis tools to demonstrate the impact of decisions. Therefore, the appropriate use of innovative technologies such as BIM to achieve value of facilities over their lifecycle is an increasingly recognised need in the industry.

Industry disaggregation, poor marketing of the value and disparate market drivers have limited the potential for a greater uptake of lifecycle thinking and innovative technologies along the supply chain. This research project seeks the integration of lifecycle thinking with innovative technologies that can help link key decisions in facility design, construction, operation and maintenance to novel decision-making support platforms.

Industry deliverables

This research project has delivered the following to industry:

1. Unlocking facility value through BIM.

This deliverable includes a comprehensive review of 33 local and global projects to illustrate the benefits of using BIM for asset management to achieve facility value. The review also identifies tools, actions or processes that have been adopted across the 33 cases to maximise the benefits of implementing BIM. This deliverable also includes a practical BIM adoption roadmap which provides details about the role of government at various stages of BIM implementation.

2. Unlocking facility value through BIM: Case study 1 – BIM in remote housing.

The Australian Government focuses on forward planning, smarter practices and the leveraging of government resources to deliver efficient services for remote regions. This case study has developed an approach to advance the use of Level 2 BIM for remote regional government housing and related infrastructure to support proactive and efficient maintenance management.

3. Unlocking facility value through machine learning: Case study 2 – Machine learning in line marking detection.

The capability of computer vision to save tedious manual work, automate image processing and generate reliable detection results can be applied in many disciplines. This case study provides the development of a computer vision technique based on machine learning to achieve automated and efficient line marking detection.

4. Unlocking facility value through lifecycle costing: Case study 3 – Lifecycle costing in road widening evaluation.

Road widening is part of Main Roads Western Australia's (MRWA's) overall plan to support population growth and economic development. This case study utilises a whole-of-lifecycle costing approach to evaluate road widening options based on agency cost, road-user cost and accident cost.

Unlocking facility value through BIM

A literature review was conducted to gain a comprehensive understanding of the application of BIM in unlocking facility value, especially in asset management. Table 1 lists the 33 case studies reviewed in this research project.

Table 1. Projects reviewed in the research project

	Project Name	Project Type
1	Denver International Airport (Colorado, US)	Airport
2	Prince Mohammad Bin Abdulaziz International Airport (Saudi Arabia)	Airport
3	Heathrow Airport (London, UK)	Airport
4	Schiphol Airport (Amsterdam, Netherlands)	Airport
5	Gatwick Airport (UK)	Airport
6	Northumbria University city campus (Newcastle, UK)	Educational
7	Flinders University (South Australia)	Educational
8	Howard Hughes Medical Institute (Maryland, US)	Educational
9	Texas A&M Health Science Center (Texas, US)	Educational
10	Sykehuset Østfold (Norway)	Health care
11	HOK Healthcare (New York, US)	Health care
12	Perth Children’s Hospital (Western Australia)	Health care
13	The new Royal Adelaide Hospital (South Australia)	Health care
14	Stanford Neuroscience Health Center (California, US)	Health care
15	East Sussex Healthcare NHS Trust (UK)	Health care
16	University of Maryland Medical Center (Baltimore, US)	Health care

	Project Name	Project Type
17	Sydney Opera House (Sydney, Australia)	Iconic building
18	M25 Motorway (London, UK)	Infrastructure
19	Crossrail (London, UK)	Infrastructure
20	Wuhan Metro (China)	Infrastructure
21	Pyrmont Bridge (Sydney, Australia)	Infrastructure
22	Maharashtra Metro Rail (India)	Infrastructure
23	A556 Knutsford-Bowdon Improvement Project (UK)	Infrastructure
24	Sydney Metro Northwest project (Sydney, Australia)	Infrastructure
25	Trafford Park Line – Crumpsall Metrolink (UK)	Infrastructure
26	MTR (Hong Kong)	Infrastructure
27	Lower Catskill Aqueduct (New York, US)	Infrastructure
28	Victoria Station, London Underground (UK)	Infrastructure
29	Wynyard Quarter Innovation Precinct (New Zealand)	Multi-functional environment
30	Ministry of Education (Kuwait)	Public building
31	IBM Japan, Osaka office (Japan)	Commercial
32	Takenaka – NTT Building (Japan)	Commercial
33	Mapletree Business-City II (Singapore)	Commercial

A total of 31 benefits were achieved across these projects and reviewed. Some of the significant benefits achieved include[1]:

- **Asset management labour utilisation savings.** In the case of the Stanford Neuroscience Health Center, a 60 per cent to 70 per cent reduction in time spent on fix-and-repair was achieved through BIM's 3D visualisation (Sacks et al., 2018).
- **Better change management.** In the past, building inspectors for Pyrmont Bridge, Sydney, had to undertake an annual condition assessment process of the 7,500+ structural components of the bridge via a manual, paper-based process consisting of paper, pens and digital cameras. With the cloud-based 3D BIM-based solution, a mobile inspection app is used to enter the data, which is then automatically synced with the 3D model used for bridge inspections (Sahlman, 2015).
- **Faster regulation and requirement compliance.** The use of BIM in the A556 project enabled a quick compliance check with the UK Government's planning process (Planning Inspectorate), as well as compliance with industry standards such as BS 1192:2007[2], BS11000-1:2010[3], BS7000-4[4], PAS1192-2[5], ISO 9001[6], ISO 55000[7], ISO 12006[8] and ISO 16739[9] (Aziz et al., 2014).
- **Better programming/scheduling.** In the Wynyard Quarter Innovation Precinct project, digital dashboards quickly and clearly tracked the contracting team's progress in uploading the required asset management data throughout the construction process. This gave the project management team true visibility of the progress of completed asset information and handover deliverables, helping to ensure that 100 per cent of critical digital information was available at the project's completion (BIMinNZ, 2016).

[1]For a complete list and description of BIM benefits and enablers, please visit the full research report available at: https://sbenrc.com.au/research-programs/2-64/
[2]BS1192:2007 Collaborative production of architectural, engineering and construction information – code of practice
[3]BS11000-1:2010: Collaborative business relationships: a framework specification
[4]BS 7000-4:2013: Design management systems: guide to managing design in construction
[5]PAS 1192-5:2015: Specification for security-minded BIM, digital built environments and smart asset management
[6]ISO 9001: 2015: Quality management systems – requirements
[7]ISO 55000: 2014: Asset management – overview, principles and terminology
[8]ISO 12006:2015: Building construction – organisation of information about construction works
[9]ISO 16739: 2013: Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries

In addition, a total of 36 benefit enablers were also identified. These enablers are shown in Table 2[1]:

Table 2. BIM benefit enablers identified from the 33 case studies

1. Design authoring and data-rich accurate models
2. Early and effective stakeholder engagement
3. Integrated model and program management systems
4. Online collaboration and project management
5. Interoperability and data formats
6. Object libraries
7. Well-structured data
8. 3D laser scanning – point cloud manipulation
9. 3D control and planning (digital layout)
10. Animations and simulations
11. Augmented reality
12. Automated clash detection (spatial and 3D coordination)
13. Automated rule-checking
14. Asset knowledge management
15. Asset performance assessment, modelling and displays
16. Asset (preventive) maintenance scheduling
17. BIM-based asset management
18. Constructability analysis
19. Construction and phase planning (4D modelling)
20. Site utilisation planning and analysis
21. Construction system design (virtual mock-up)
22. Cost estimation (quantity take-off) and planning (5D)
23. Design reviews
24. Digital fabrication
25. Disaster planning and response/disaster analysis
26. Field and management tracking
27. Front-end planning
28. Geographical Information System GIS-BIM
29. Handheld devices
30. Information delivery manuals
31. Lean construction principles
32. Life cycle costing
33. Photogrammetry
34. Radio-frequency identification (RFID)
35. Space management and tracking
36. Streamlined logistics

Case study 1

Unlocking facility value through BIM: BIM in remote housing

The building industry has been gradually transitioning towards digital asset management practices which are often complicated by a lack of consistent models for gathering and maintaining up-to-date asset information across the industry.

This case study aims to develop an approach to advance the use of Level 2 BIM for remote regional government housing and related infrastructure to support proactive and efficient maintenance management. Data collection involved conducting semi-structured interviews with Queensland Department of Housing and Public Works (QDHPW) representatives, followed by several stakeholder workshops. In order to develop a functioning Level 2 BIM 3D model, a previously developed 3D model for a typical public duplex house (as shown in Figure 1) was requested and retrieved. Then, manuals, certificates, approvals and services schedules were collected and analysed.

Specific implementation strategies were proposed in this case study. For example, when assigning asset information to the BIM model, measurements and asset information were retrieved from QDHPW documents and later assigned to the model. Element description, comments, manufacturer, model series and name, together with price per unit and a URL link to a manufacturer website with the product was also added to the object (Figure 2). The inspection certificates and manual could not be assigned as a hyperlink or as text, so it was added to the object description as images (Figure 3).

Figure 1. 3D model of a typical public duplex house in Case Study 1

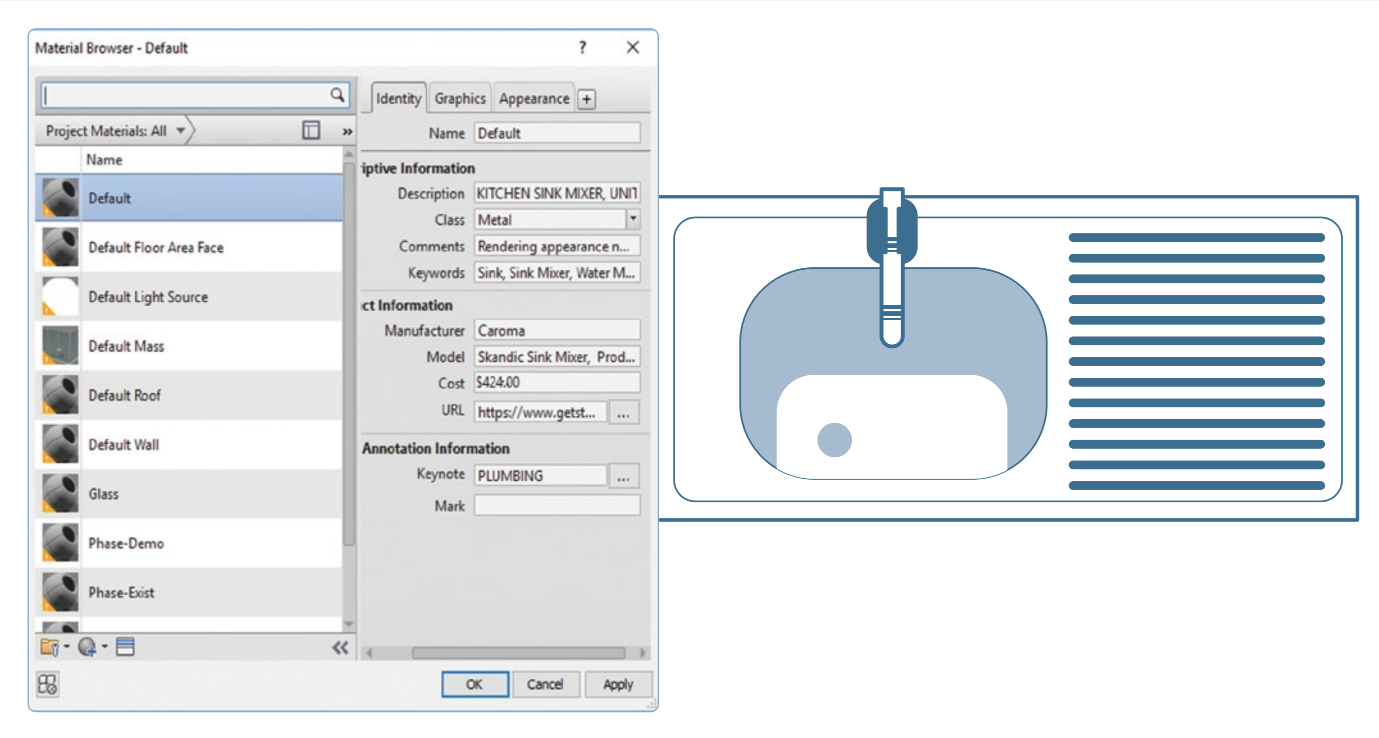


Figure 2. **An example of assigning asset information to the BIM model: water mixer information**

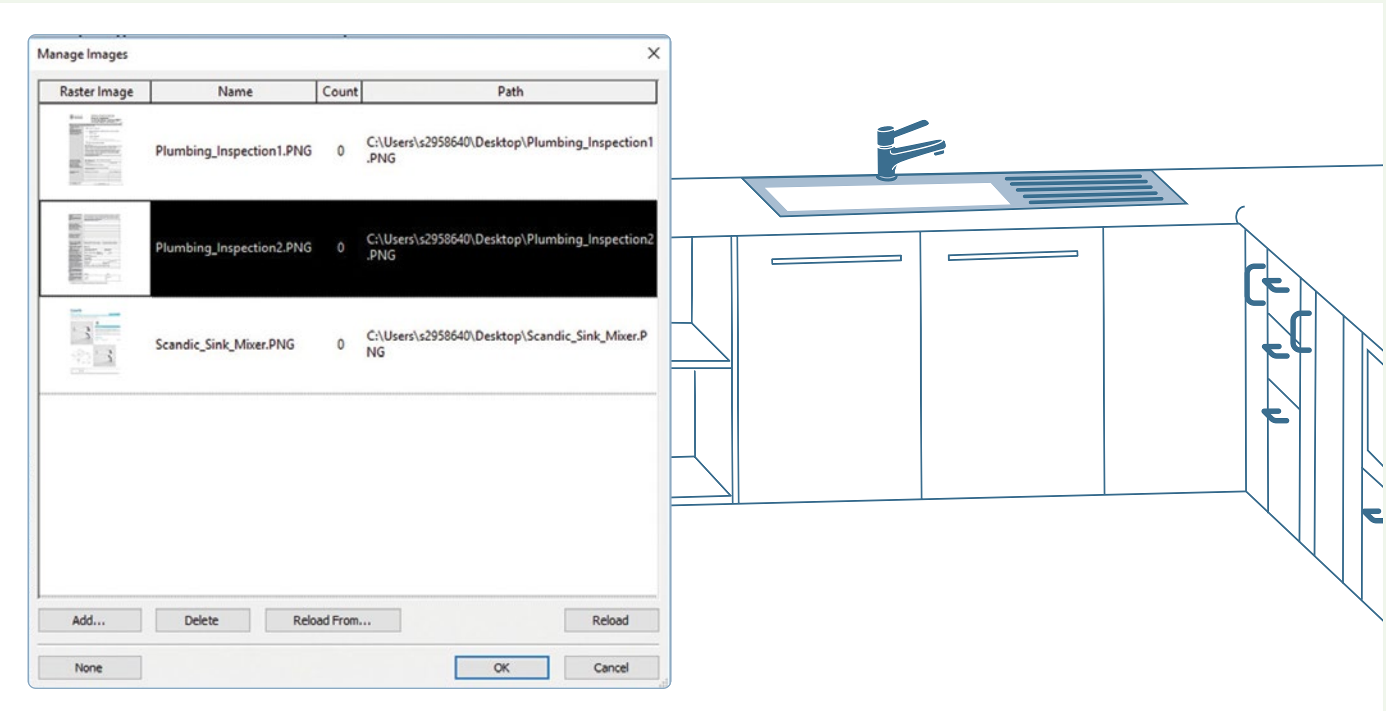


Figure 3. **An example of assigning asset information to the BIM model: water mixer inspections and manuals**

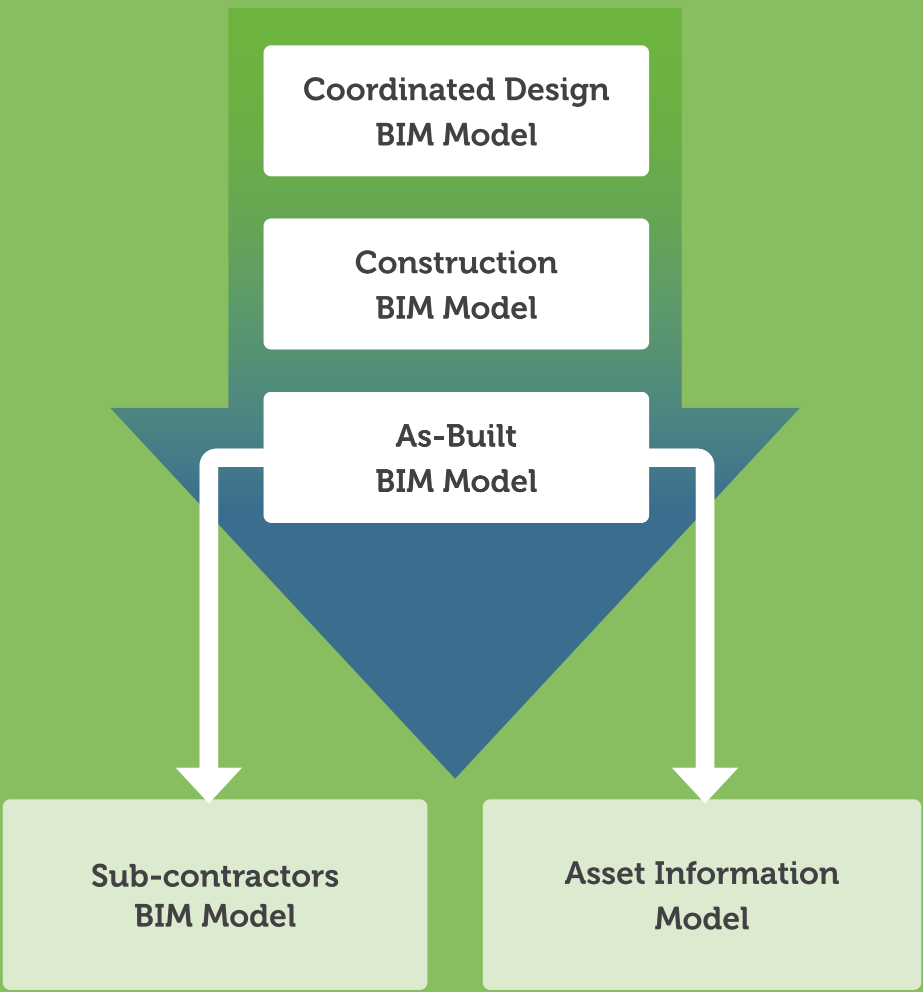


Figure 4. Evolution of data and BIM implementation for small housing projects

A model for the implementation of BIM through the lifecycle of newly built houses was proposed (Figure 4). Such model ensures that a maximum amount of information could be collected in regard to the buildings and small public housing projects, which would be an ideal point to start the gradual adoption of BIM. The model comprises a series of models for the various stages of construction, as follows:

- The first model to be developed is a design model with the required Level of Detail 350.
- The second model would be used before and during the construction phase.
- The third as-built model would be a construction model with updated elements to match an actual building.
- The final model is the completed model with the desired level of information assigned to elements.
- Additionally, an optional model for subcontractors could be created to ease interaction with the model and to ensure confidentiality of the data.

It was also proposed in one of the stakeholder workshops to reverse engineer the asset management model and to state all the required information for efficient facility management before the start of the construction phase to ensure collection of all the relevant information from the site.

Participants suggested that not only is it crucial to ensure the safety and comfort of housing tenants, but also to cut expenditures on maintenance of those assets. Economic evaluation showed that the most critical assets requiring focus and constant condition assessments in remote regions are air-conditioning, building structure components, internal and external finishes, and site upgrades. It was determined that the operation and maintenance of government houses in remote communities would benefit mostly from cutting the costs for defects and failures associated with unsuitable material or design, non-compliance with codes and standards groups, a lack of maintenance, age and normal wear and tear.

The following key benefits were identified for BIM implementation in the operation and maintenance stage of small housing projects:

- resource saving within the department
- resource saving by contractors
- reduced number of incidents with severe damage or damage caused by the fault of another element
- improved statistical data collection and evaluation
- easy-to-use Unite ‘ecosystem’ within the organisation
- better understanding of assets
- improved asset management operations
- enhanced quality of maintenance services for public houses.

Case study 2

Unlocking facility value through machine learning: Machine learning in line marking detection

Pavement markings and signs constitute the most fundamental way to communicate with road users and they are, in most cases, the most effective way to regulate, warn and guide traffic. In this project, a machine learning technique was developed to achieve automated and efficient line marking detection.

Four sets of pavement images (51 images in total) were collected at the beginning of the project. The sample images cover road pavement in both rural and urban areas. Figure 5 shows a typical image from the dataset.

The developed vision-based line marking detection method consists of four steps, namely 1) image pre-processing, 2) feature extraction, 3) segmentation and 4) line marking classification, as shown in Figure 6.

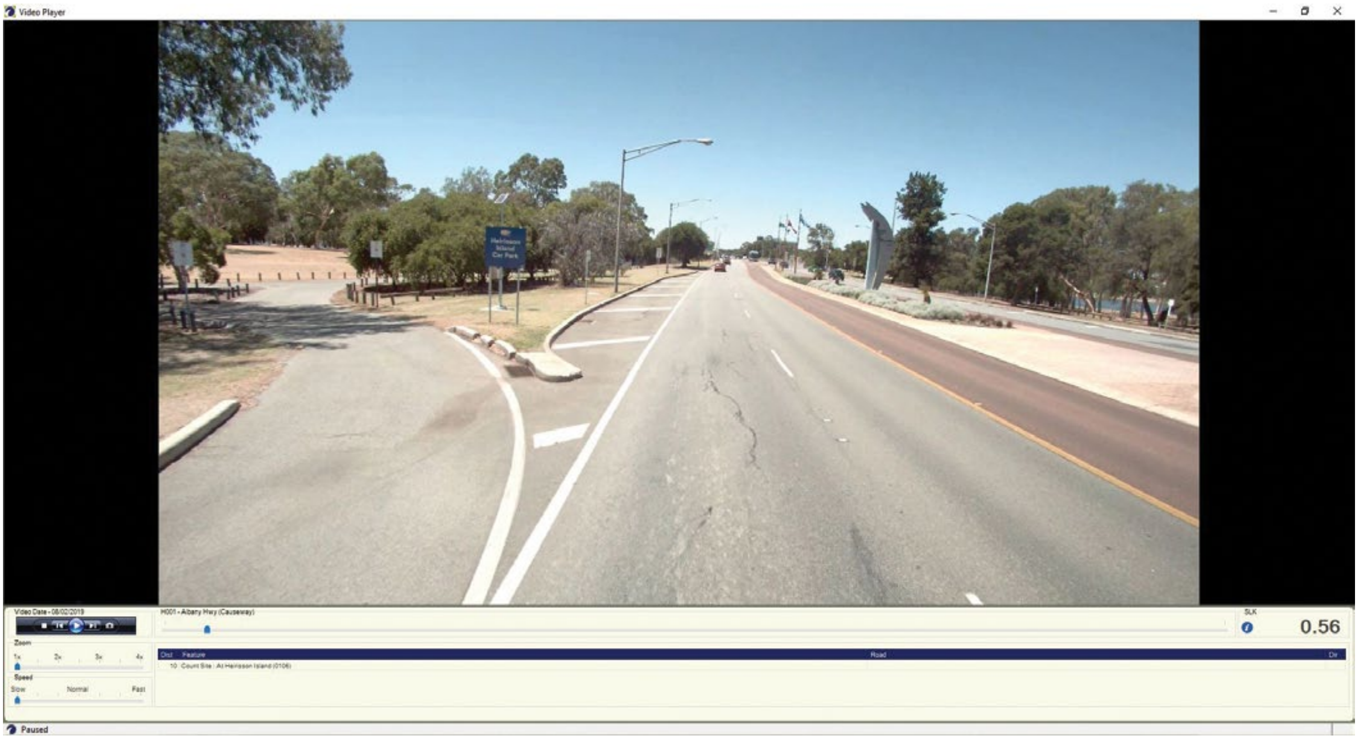


Figure 5. **A typical data image in the dataset of Case Study 2**

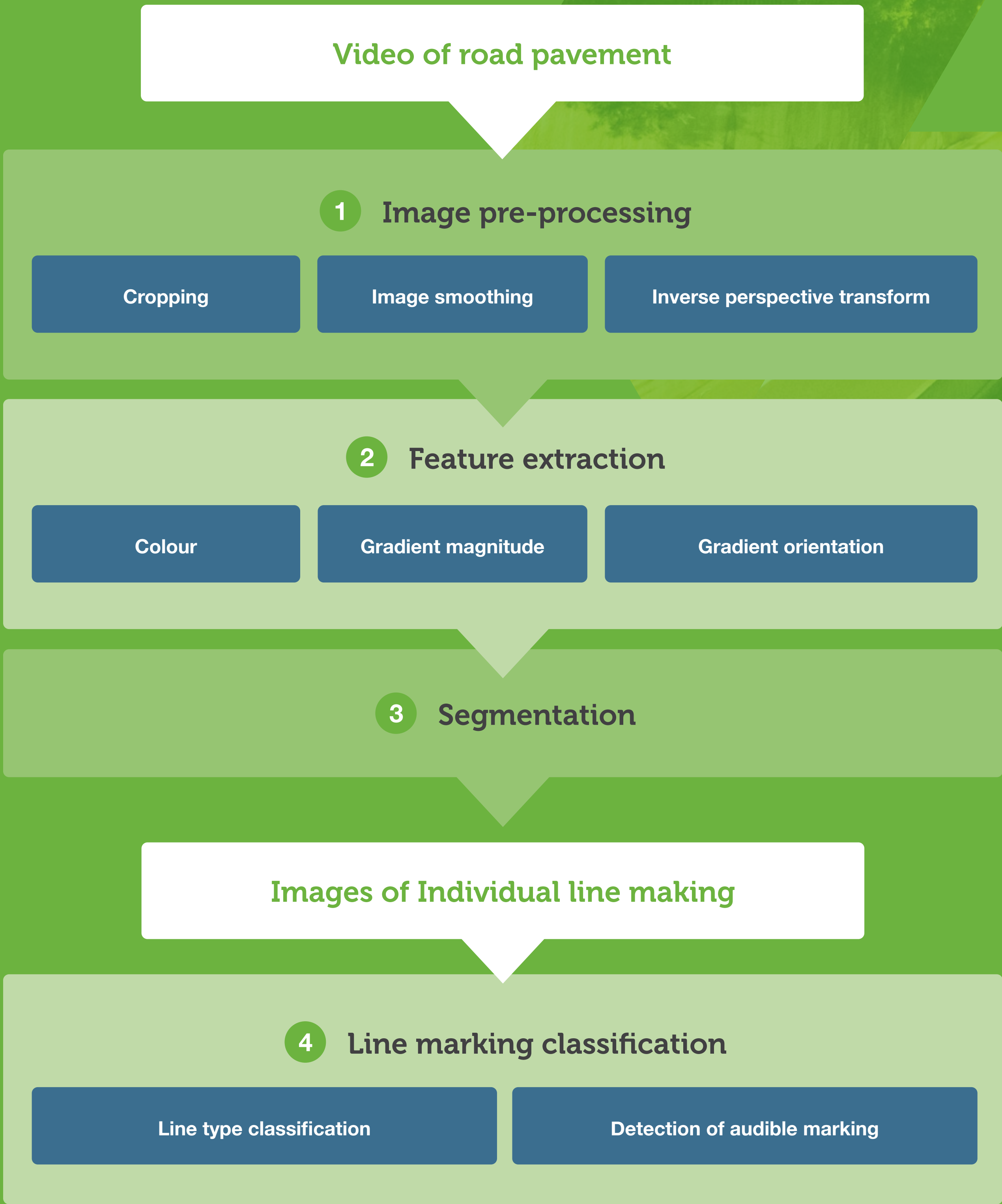


Figure 6. The machine learning method developed in Case Study 2 to identify line marking

Table 3 presents results from the project relating to the detection of line marking for urban roads. For each line marking instance in each image sample, the colour, line type, presence of audible markings and worn condition estimation are listed. The method can successfully identify the line types and their worn percentages at a satisfactory level.

Table 3. Detection of line marking results for urban roads in Case Study 2

NO.	Line marking_1		
	Colour	Type	Worn
a01	white	continuous	0.183312263
a02	white	continuous	0
a03	white	short-dashed	0.035714286
a04	white	short-dashed	0.047244094
a05	white	short-dashed	0.070707071
a06	white	short-dashed	0.13740458
a07	white	continuous	0.027465668
a08	white	continuous	0.132334582
a09	white	continuous	0.037453184
a10	white	continuous	0.031210986
a11	white	continuous	0.126092385
b01	N/A	kerb	N/A
b02	N/A	lane widening	N/A
b03	N/A	lane widening	N/A
b04	N/A	kerb	N/A
b05	N/A	kerb	N/A
b06	N/A	lane widening	N/A
b07	N/A	lane widening	N/A
b08	N/A	kerb	N/A
b09	N/A	kerb	N/A
b10	N/A	kerb	N/A

	Line marking_2			Line marking_3			Line marking_4		
	Colour	Type	Worn	Colour	Type	Worn	Colour	Type	Worn
	white	long-dashed	0.086486486	yellow	continuous	0.09113608			
	white	continuous	0.563302752	yellow	continuous	0.098626717			
	white	long-dashed	0.2	yellow	continuous	0.142322097			
	white	long-dashed	0.111111111	yellow	continuous	0.168539326			
	white	long-dashed	0.176829268	yellow	continuous	0.153558052			
	white	long-dashed	0.113300493	yellow	continuous	0.183520599			
	white	long-dashed	0.064171123	yellow	continuous	0.252184769			
	white	long-dashed	0.011976048	yellow	continuous	0.551928783			
	white	long-dashed	0.039106145	yellow	continuous	1			
	white	long-dashed	0.074468085	yellow	continuous	1			
	white	long-dashed	0.015873016	yellow	continuous	0.908496732			
	white	long-dashed	0.039548	white	short-dashed	0.324324	N/A	kerb	N/A
	white	long-dashed	0.04	white	short-dashed	0.471698	N/A	kerb	N/A
	white	long-dashed	0	white	short-dashed	0.644444	N/A	kerb	N/A
	white	continuous	0.463855	white	short-dashed	0.561798	N/A	kerb	N/A
	white	continuous	0.191011	white	continuous	0.265918	N/A	kerb	N/A
	white	short-dashed	0.926506	white	short-dashed	0.850602	N/A	kerb	N/A
	white	short-dashed	0.926506	white	long-dashed	0.394737	N/A	kerb	N/A
	white	short-dashed	0.828916	white	long-dashed	0.274699	N/A	kerb	N/A

Case study 3

Unlocking facility value through lifecycle costing: Lifecycle costing in road widening evaluation

Road widening is part of MRWA's overall plan to support population growth and economic development. A road widening project can include the construction of noise walls, upgrade and realignment of existing paths, and modifications to road infrastructure assets including drainage, kerbing, surfacing, lighting, road safety barriers, service relocations, signage and line marking. The evaluation of road widening projects should be based on a lifecycle consideration.

The lifecycle costing, or whole-of-life costing approach, is adopted to include consideration of the following cost elements:

- Agency cost. Agency cost includes all costs incurred by the agency over the analysis period. In this project, the agency cost refers to the unit rate of road widening including seal widening, pavement widening and seal maintenance. Such cost data are provided by MRWA.
- Road user cost. The road user costs associated with an investment option covers all the costs incurred by users over the analysis period and include vehicle operating costs, travel time or delay costs due to reduced speeds and/or the use of alternate routes. The evaluation of road user costs follows the Australian Transport Assessment and Planning Guidelines (Transport and Infrastructure Council, 2016).
- Accident cost. The accident cost and potential reduction of accident rate are evaluated based on the Road Trauma Treatments Guideline from MRWA (2019).

The approach was then used to evaluate whether a low-cost option or ultimate option would be implemented at which road segments so that an optimal benefit/cost ratio can be achieved. In this case study, 'benefit' is defined as a reduced road user cost (RUC) and accident cost when road segments are widened. 'Cost' is defined as the agency cost for relevant road widening options.

Some significant findings are:

- The RUC saving of road widening is significantly small when compared to the accident cost saving when a road widening strategy is adopted. In addition, very minimal difference is identified when an ultimate option is adopted compared to a low-cost option in terms of RUC saving.
- An ultimate cost option generally has poor value, as it significantly reduces the benefit/cost ratio. This is due to the significant increase in agency cost when an ultimate option is selected.
- Some road segments have very good benefit/cost ratio for widening. The road segments with the highest benefit/cost ratio (low-cost option) are highlighted in Table 4.

Table 4. **The lifecycle cost and benefit/cost ratio of road widening options in various road segments**

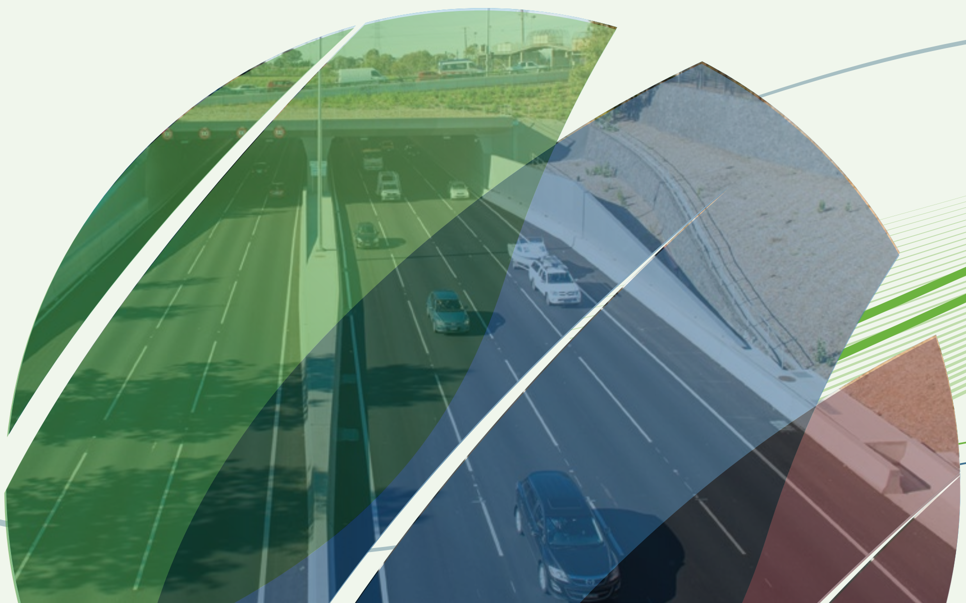
Name	No.	From SLK	To SLK	Agency cost		Road user cost			Accident cost			Seal maintenance		B/C ratio	B/C ratio
				LO	UO	LO	UO	Current	LO	UO	Current	LO	UO	LO	UO
Albany Hwy	H001	51.2	158.7	1.08m	25.16m	1.44m	1.43m	1.42m	176.97m	106.25m	107.93m	0.5m	1.15m	44.9	2.6
Bussell Hwy	H043	101	140.73	0.52m	2.10m	0.43m	0.43m	0.43m	26.89m	10.60m	10.60m	0.36m	0.36m	18.6	6.6
Great Eastern Hwy	H005	56.43	89.11	2.83m	12.10m	0.71m	0.71m	0.71m	64.20m	25.80m	25.80m	0.30m	0.30m	12.3	3.1
Vasse Hwy	M008	57.51	92.99	5.23m	37.40m	0.07m	0.07m	0.07m	135.60m	57.02m	55.62m	0.32m	0.54m	14.15	2.11
Vasse Hwy	M008	92.99	125.5	6.36m	55.43m	0.03m	0.03m	0.03m	113.85m	51.27m	39.01m	0.29m	0.69m	9.41	1.33

Note:

LO = low-cost option

UO = ultimate option

B/C = benefit/cost



Industry benefits

This research project has established the use of lifecycle thinking, supported by other innovative approaches and technologies including BIM, machine learning and whole-of-life costing to realise facility values.

Specifically, the project has demonstrated industry value for housing, building and road agencies at various levels, including:

- A comprehensive list of BIM benefits and benefit enablers, evidenced from 33 industry case studies. It is an evidenced-based resource related to the tools, actions or processes that can facilitate the implementation of BIM and maximising its benefits.
- An early machine learning proof-of-concept for line marking detection. The developed vision-based line marking detection method is a computer vision technique that has satisfactory capability to save tedious manual work, automate image processing and generate reliable detection results.
- A whole-of-life costing approach and implementation in the evaluation of road widening options. The whole-of-life costing approach developed and implemented in this project has proven to be effective in comparing competing investment options over a certain analysis period and identifying the option that results in the minimum total lifecycle cost.

While the approaches and methods in this research project have been developed to address specific problems faced by the industry partners to the project, the results are useful for other industry agents who aim to incorporate data-driven and whole-of-life considerations into their decision-making processes, and to develop training and educational materials to build capability to explore the benefits.

Conclusions and next steps

This SBEnrc research project has provided those working in the housing, building and infrastructure sectors the necessary approaches and tools for considering the impact of decisions on the lifecycle of projects. Specifically:

- Through a comprehensive review of 33 local and global projects, the adoption of BIM for asset management to achieve facility value and tools, actions or processes in each case has demonstrated the maximal benefits of its implementation.
- Using a case study approach, a process to advance the use of Level 2 BIM for remote regional government housing and related infrastructure to support proactive and efficient maintenance management has been developed.
- Two approaches to integrate machine learning and whole-of-life costing in lifecycle thinking have been developed and tested in two scenarios: line marking detection and road widening option evaluation.

Our industry partners have participated in the development and implementation of these approaches to truly integrate innovative technologies into their decision-making processes.

Moving forward, we encourage more industry practitioners to implement these models and provide valuable feedback to realise the full potential of lifecycle thinking in the built environment.

Project Steering Group Chair's Statement

"This project has demonstrated how digital platforms can be applied to enable full access to the value of facilities throughout their lifecycles. It has shown that this approach is valid for traditional vertical infrastructure as well as portfolios of smaller facilities and longitudinal transport facilities. This was achieved through a series of representative case studies and an innovative approach to employing Artificial Intelligence methods. The success of the project results from a productive partnership among research, industry and policy agencies. This has been a successful project and now provides the springboard for development of a unified BIM solution through a structured and integrated data approach which has national consistency and overseas compatibility."

— **Steve Golding AM, RFD**

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